THE

PRINCIPLES AND PRACTICE

OF

ELECTRIC LIGHTING

BY

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PREFACE.

THERE ARE three classes of people interested in Electric Lighting: the engineers and scientists, whose duty it is to invent, improve, and erect the necessary machinery and apparatus; the employers, who use the light; and the general scientific public, who take an interest in all new discoveries and inventions. The aim of the Author has been to write a book to meet the wants of the two latter classes—a book which should be on the one hand sufficiently simple and devoid of technicalities to be easily understood by unscientific readers, and on the other sufficiently comprehensive and up to date to give reliable information on all the principal appliances and systems.

In works of this kind it has hitherto been customary to give detailed and tedious descriptions of obsolete machines of no practical value whatever, which tire the reader and render necessary the omission or curtailment of the accounts of more modern and more important inventions. The Author has tried as far as possible to avoid this error, and with one or two necessary exceptions everything treated is of modern interest.

It is hoped that some portions of the book will be of use to those who propose adopting the electric light, in giving them some insight into the theory and practice of the subject, and in helping them to decide which of the different systems is most likely to suit their requirements. The appended list of terms

will probably be found useful by those who read the subject for the first time.

The best thanks of the Author are due to Mr. WILLIAM CROOKES, F.R.S., who, as an eminent scientific authority and practical electrician, has made many important suggestions and rendered very valuable assistance in the task of preparing the work for the press.

The Author is also indebted to the Editor of the 'Electrician,' Messrs. Siemens, Messrs. Crompton, Messrs. Robey, Messrs. Paterson & Cooper, the Brush Electric Light Corporation, the Edison Electric Light Company, the Pilsen-Joel Electric Light Company, the British Electric Light Company, and others, from whom he has received information and assistance.

ALAN A. CAMPBELL SWINTON.

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ELECTRIC LIGHTING.

CHAPTER I.

INTRODUCTORY.

RECENT EVENTS seem to point to Electricity as the illuminating agent of the future. The electric light is at present being rapidly adopted in all parts of the world, and in the opinion of most competent persons there is no longer any reasonable doubt, that exactly in the same way as gas has now all but superseded candles and oil, so in turn, before many years have passed, gas will have to give way to electricity.

Electric lighting has now passed the purely experimental stage of its existence, and though further improvements are still to be expected, very tangible results have already been attained.

The Paris Electrical Exhibition of 1881, and the more recent exhibitions at the Crystal Palace, the Westminster Aquarium, and the Fisheries Exhibition in England, have done great service in demonstrating the practicability of the new agent, while the numerous electric installations that have been erected in public and private buildings, together with the lighting by means of electricity of a large number of streets and thoroughfares, have shown that the new light can be perfectly adapted to suit different requirements.

The progress of electric lighting has, however, met with much opposition, and its adoption has been considerably hindered, not only by the unwarranted assertions of interested rivals, but also in many cases by the over-enthusiasm of apparent friends. On the one hand the upholders of the gas interests and other persons who have reason to fear the introduction of

a new illuminant, have done everything in their power to disparage lighting by electricity. They have stated that the system is unavoidably dangerous, that its results are unbecoming and harsh, that its working is impracticable, while according to their account the enormous expense entailed renders its general adoption entirely out of the question. The answer to their objections will be found in the following pages, and the reader will be able to judge whether the faults they find are real or imaginary.

The progress of electric lighting has moreover been greatly delayed by the inevitable results of speculation. Of the numerous companies that were formed a very few years ago, in order to undertake the installation and maintenance of electric lighting machinery, not a few have failed, not only in the realisation of the somewhat extravagant hopes of their promoters, but in the realisation of any success at all. The reason for this discouraging state of matters is easy enough to see. The greater number of these unsuccessful companies subscribed vast sums of money in order to purchase patents, which at the time no doubt seemed of great value, but which have proved to be of scarcely any value whatever. There is perhaps no more intricate subject than that of patents. The rewarding of inventors is undoubtedly a very difficult question, for whole lifetimes and immense sums of money are frequently expended in the perfecting of inventions, which, though of great importance and value, cannot easily be protected by patent. Patents, moreover, are always liable to be superseded by fresh discoveries, and they often lead to prolonged and extensive litigation, the expense of which is generally very great, while the results are most uncertain.

Now, companies who have paid large sums of money for patents, cannot hope to compete with those whose expenses have been less, except indeed the patents held by the former give them an undoubted monopoly to manufacture or employ inventions of paramount importance. Thus it is that companies who have purchased patents that have turned out of little or no value have been unsuccessful, and have had to make way for others whose patents have been found to be of greater

intrinsic worth, or at all events of a value commensurate to their cost, and for those who have not paid for patent rights at all. In this as in all other cases of a similar nature it is merely a question of the survival of the fittest.

To pass on to more practical considerations. Electric lighting in towns is at present upon much the same footing as it is in the country districts, but this state of matters is not likely to last for long. Electricity, like nearly everything else, can be more economically generated on a large than on a small scale. It therefore seems likely, and the provisions of the Electric Lighting Act of last year add strength to the supposition, that in towns large central stations, capable of supplying great numbers of electric lamps, will shortly be established, the electricity being distributed over a large area in a manner similar to what is now the case with gas and water. In the country districts, on the other hand, this will probably be impossible or at any rate inconvenient, owing to the greater distance between the residences of the different consumers, and every separate village or country house will consequently require a complete installation for itself.

At present owing to various causes the central station system has been established in only a very few places and on a small scale, and hence even in towns consumers require to generate their own supply of electricity. However, as already stated, this cannot last for long, and before many years have passed it is probable that central stations, with a complete system for distributing electricity throughout the surrounding districts, will exist in all the larger towns of the United Kingdom. Then, and not till then, will the full advantages of electricity as an illuminating agent be adequately realised.

The whole system of modern electric illumination is dealt with in the following chapters; the nature and effects of electricity, the manner of its generation, and the ways in which it can be made to furnish light being first given. Throughout the remainder of the book are described more or less in detail all the principal modern generators and lamps, together with conductors and the other appliances required in electric light installations.

CHAPTER II

THE THEORY OF ELECTRIC LIGHTING.

The Nature of Electricity—The Different Ways in which Electric Energy can be Produced—Current—Potential—Electromotive Force—Conductors—Insulators—Positive and Negative Poles of Circuits—Galvanic Batteries—Galvanometers—Electro-magnetism—Magneto-electricity—Magnetic Fields—The Gramme Ring—The Siemens Armature—Dynamo-electric Generators—The Electric Arc—Incandescence of Conductors—Incandescent Lamps—Electric Lighting Installations.

VERY little is at present known as to the true nature of electric action. Electricity has been regarded by some scientists as a subtle and imponderable fluid pervading everything, while others have considered it to be a combination of two fluids. A more recent and perhaps more satisfactory theory is that electricity is a form of molecular disturbance, as are light and heat. We do not know what electricity is, we only know what it does; yet this for all practical purposes is quite sufficient. Whether, however, we accept the fluid doctrine or not, we shall on the whole find it convenient to call it a fluid, and treat it as though it were one.

Electric energy may be produced in several different ways. What is known as frictional or static electricity is generated by the rubbing together of dissimilar substances; galvanic electricity is the result of chemical action; thermo-electricity is produced by the action of heat upon metals; while magneto- or dynamic electricity is obtained by the combined influence of magnetism and mechanical energy. It is with the last of these that we have mostly to deal, for it is dynamic electricity that is chiefly employed in electric lighting.

It must not, however, be thought that these various names denote kinds of electricity that are in reality different from

one another; the electricity is all the same, and it is only the means for producing it that varies. The only reason why magneto- or dynamic electricity is more suited than the others for electric lighting, is that the dynamic method of producing the fluid is more economical than the others. Galvanic or voltaic electricity is, however, also occasionally made use of.

Although, as we have mentioned above, the term fluid may not be theoretically correct, yet it is a very convenient nomenclature, for electricity may be said to flow along certain substances in very much the same manner as a fluid flows in a pipe. A flow of electricity along a substance is usually called *a current.*

When a certain amount of electricity is applied to an isolated body, the body is said to be electrified. *Potential* is the term employed by electricians to denote the work required to convey unit of negative electricity against the electric attractions from that point to an infinite distance. Therefore *difference of potentials* at any two points is the work required to carry unit of negative electricity from one to the other (Tait).

Electromotive force is the term used to denote that which tends to produce a flow or current of electricity from one part of a body to another. Exactly as in a water-pipe a difference of head or level produces a pressure which tends to cause a flow of water from where the head is high to where it is lower, so a difference of potential in the electricity pervading a body produces an electromotive force which tends to produce a current of electricity from where the potential is high to where it is lower.

Any substance through which an electric current can readily flow is called a *good conductor*, while a substance through which the current can only pass with great difficulty is called a *bad conductor* or *insulator.* The word non-conductor, which is sometimes used, should be avoided, as no substance has yet been discovered through which an electric current is absolutely incapable of passing. Silver, copper, iron, and most of the metals are instances of good conductors; while glass, ebonite, ivory, and other substances are insulators.

Resistance is the opposition or obstruction that a current

meets with when flowing through a conductor. All substances offer a certain amount of resistance, but some very much more than others.

The strength of a current flowing along a conductor is found by dividing the electromotive force of the electricity by the resistance of the conductor forming the circuit or path followed by the current.

When one part of a circuit is charged with electricity of higher potential than the rest, and a current is consequently flowing from the higher to the lower, the former is called the *positive* and the latter the *negative* pole of the circuit.

It has already been mentioned that it is now not usual to employ the electricity derived from a galvanic battery for electric lighting. This is owing to the fact that batteries are very troublesome and costly to maintain, while electric energy can be generated in far greater quantities, and at less expense, by dynamic means. The earlier investigators into electric science, however, employed batteries almost exclusively. For this reason, and also because it will help the reader to understand some of the electric phenomena to be described later on, it will be as well to explain here the principles of a simple battery.

If two plates of dissimilar metals, such as copper and zinc, be immersed in a jar containing sulphuric acid diluted with water, we have a very simple form of electric battery. If the two plates be connected together by means of a copper wire, some curious phenomena present themselves. In the first place, numbers of small bubbles of hydrogen appear on the surface of the copper, from which they eventually detach themselves, rise, and burst at the surface of the solution. If the wire connecting the plates be severed, this chemical action at once ceases, but the moment the two ends of the wire are again brought into contact, it commences once more. The reason for this is as follows. As long as the wire is continuous, the copper or positive pole of the battery is maintained in a state of higher potential than the zinc or negative pole. A current is therefore set up in a circuit from the copper plate through the wire into the zinc, and then back again into the copper through the acidulated water. This produces a chemical

action which liberates the hydrogen of the water in bubbles, which attach themselves to the surface of the copper plate. The moment, however, the circuit is interrupted, and the electric current ceases to circulate, the chemical action is arrested.

The current produced by a battery uch as this is in reality very slight indeed, but other forms of very great power have been perfected by Grove, Bunsen, and other scientists. As battery currents are now but rarely employed for electric lighting, it will be needless to describe any of these non-practical forms of galvanic batteries, and we may therefore now pass on to consider some of the phenomena which are observed when dealing with electric energy.

In fig. 1, a coil of wire, A, each turn of which is insulated from its neighbour by being wound round with silk- or cotton-thread, is made to inclose a magnetised steel compass-needle,

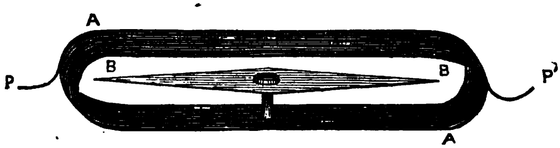

FIG. 1.—Galvanometer.

B, which is free to turn in any direction. Now, if the potential of one pole, P, of the coil be maintained higher than the potential of the other pole, P′, a current of electricity will circulate round the coil from P to P′. This can be readily brought about by connecting P to the positive and P′ to the negative pole of a small battery. Now, if in the first instance the compass-needle be parallel with the convolutions of the coil, the instant the current commences to flow the needle will swing round and tend to place itself at right angles to its former position, and will remain thus till the circuit of the battery is interrupted and the current consequently ceases, when it will return to its original position.

Again, if instead of connecting P with the positive pole of the battery and P′ with the negative pole, the opposite is done, and the current flows from P′ to P, the needle will be found to

turn in an angular direction opposite to that in which it revolved in the first instance. When the difference of potential at the two poles is great, and the current consequently strong, the angular displacement of the needle will be greater than when the contrary is the case. By means of an instrument such as this it is therefore possible to detect the presence of an electric current in a conductor, and also to determine the strength of the current and its direction.

Instruments based upon this principle are largely employed by electricians, and are called galvanometers.

The phenomena of electro-magnetism and magnetic induction next claim consideration.

If a hollow coil of insulated wire such as A, fig. 2, the free ends of which, P, P′, are connected with a galvanic battery, be made to inclose a rod or bar of soft iron, B, it is found that the latter becomes magnetised, and remains in a magnetic state so long as the current from the battery continues to circulate in the coil. Moreover, if when the current is from P to P′ the upper end of B becomes the north pole and the lower end the south pole of the electro-magnet, the contrary is the result when the current is from P′ to P.

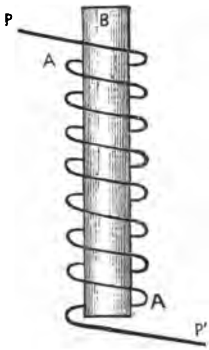

FIG. 2.
Electro-Magnet.

Next, let P and P′ be connected with the terminals of the coil of a galvanometer such as has been described above; the two coils will then form a single circuit.

Now, instead of the soft-iron rod B, let us introduce the north pole of a permanent steel-bar magnet into the coil. An immediate deflection of the magnetic needle of the galvanometer is the result. When the magnet is brought to rest, it will be noticed that the needle returns to its original position; while if the former be now withdrawn from the coil, the needle is deflected in the opposite direction. This clearly shows that when the magnet is introduced into the coil a current is made to flow in the wire of the latter; when the motion of the magnet is stopped the current ceases, and when the magnet is withdrawn

the direction of thc current is reversed. Again, it is found that the introduction of the north pole of the permanent magnet into the coil produces a current in the same direction as the withdrawal of the south pole, and *vice versâ.*

The results are also similar if the magnet be stationary and the coil moved, or if both magnet and coil be moved in opposite directions. The same effects are also observed, only in a greater degree, if a soft-iron core be placed within the coil, and the pole of the magnet simply made to approach or recede from its extremity.

Magneto-electric generators in which coils such as the above are rotated in front of powerful permanent magnets were first invented by Clarke, and are still largely employed for producing electric currents for medical purposes.

The nature of induced electric currents may be further explained as follows. Every magnet is surrounded by a magnetic field, or space, through which it exerts its influence, this field being in turn traversed by what are called lines of force. These latter are no mere imaginary lines, but can be rendered visible to the eye. If a piece of card or paper be placed above a permanent magnet, and iron filings sifted on to its surface, it is at once observed that these filings arrange themselves along certain symmetrical lines on each side of the magnet. These are the lines of force mentioned.

Now, when a coil of wire is moving in a magnetic field so that the number of the lines of force that cut the coil is at every instant increasing, an electric current in a certain definite direction is induced in the coil. Again, when the opposite is the case, and the number of lines that cut the coil is on the fall, the direction of the current is reversed. Moreover, the stronger the magnet is, the more intense is its magnetic field, and consequently the more numerous are the lines of force ; therefore, the stronger the magnet, the stronger will be the induced current. And again, the greater the number of convolutions in the coil, the more numerous are the parts in which the current is induced, and therefore the greater the total inductive effect. Hence, the greater the number of convolutions in the coil, the more powerful is the current.

However, as the wire that forms the coil must have a certain amount of resistance, any increase in the length of the wire makes the total resistance greater. The length of the coil should not therefore pass a certain limit, or the increase in resistance will more than compensate for any advantages gained otherwise.

Hence, to obtain an armature consisting of coils of the proper dimensions, revolving in an intense magnetic field, in such a way as to cut a maximum number of lines of force, has been the aim of modern electricians in designing dynamo-electric generators.

We now have to consider an invention which may be said before all others to have contributed to the possibility of lighting by means of electricity, because it was the first practical machine by which electricity could be generated on a large scale. The principles, moreover, involved in what is called after its inventors the Pacinotti and the Gramme ring, are embodied in several of the best electric generators of the present day.

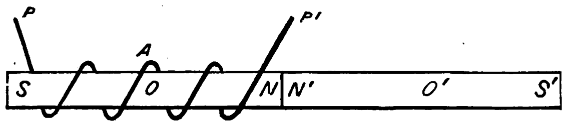

FIG. 3.

Fig. 3 will help us to understand its action. S N and N′ S′ are two similar bar magnets placed with their two north poles, N and N′, together. A is a coil or helix of insulated copper wire, which can slide backwards and forwards over the magnets from end to end. O and O′, being the middle points of the two magnets, denote their neutral or non-magnetic parts. P and P′, the two extremities of the coil, may be joined to a galvanometer.

Now, if the coil A be made to slide from S to O, a current in a certain direction will be induced in the wire, producing a corresponding deflection of the galvanometer needle. If the motion of the coil be continued from O to O′, the current will be reversed in direction, and this reversal will be maintained till after O′ has been passed, when the needle of the galvano-

meter will once more denote the presence of a current in the same direction as when the coil was moving from S to O.

Now, suppose that the two magnets are each bent into a semicircular form, so that together they form a ring, and instead of sliding the coil over the magnets, let the magnets revolve in the coil. The conditions being exactly as before, an alternating current, that is to say, a current the direction of which periodically changes, will be induced in the coil; and as long as the ring continues to revolve this current will be maintained.

Fig. 4 represents the Gramme ring, which is an application of the above principle. N′ S′ is a soft-iron ring, which is free to revolve on an axis. N and S are the poles of a permanent magnet. These poles have an inductive effect upon the soft iron of the ring, and induce poles of opposite polarity to themselves in it. Thus N, the north pole of the magnet, maintains that part of the ring nearest to it, S′, in a state of south polarity. On the ring, and attached to it, is an endless coil of insulated copper wire, the outer convolutions of which have been denuded of their insulating covering. On these uninsulated coils two fixed brass springs or brushes, P P′, are caused to rub at the diametrically opposite points A and B. Now, it will be observed that even if the ring be caused to revolve, those parts of it which are respectively opposite to N and S, the north and south poles of the permanent magnet, will always remain of south and north polarity. Hence, when the ring and its surrounding coil revolve, the polarity of the former remains fixed as regards the permanent magnets, but as regards the ring itself may be considered as flowing through the coil in a direction opposite

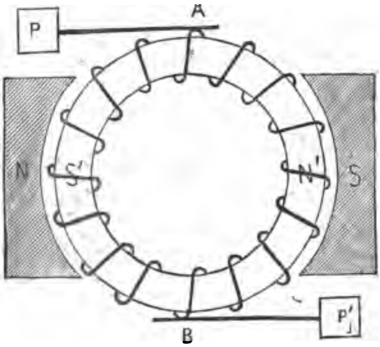

FIG. 4.—The Gramme Ring.

to that in which the latter is turning. We have, therefore, a case almost exactly similar to the stationary coil and revolving semicircular magnets described above. There is, however, one important difference. In the former case, the current was found to be alternating; now the current produced by a Gramme ring is constantly in one direction. A moment's consideration of the figure will show this. It is evident that if the ring be revolving in a certain definite direction, a current will traverse the coil in the direction A S′ B, while another will pass in the contrary direction, A N′ B. If then P and P′ be connected together, a current equal to that in A S′ B plus that in A N′ B will be set up through the springs in the direction P′ P. P′ will therefore be the positive and P the negative pole of the generator. The current thus generated is also strengthened by a further flow of electricity that takes place in exactly the same direction, owing to the direct inductive effects of the poles N and S of the permanent magnet on the convolutions of the coil, without any regard to the iron ring at all. As each convolution of the coil rises from N to A—supposing the ring to be revolving in the same direction as the hands of a watch—the number of lines of force that cut it are at every instant increasing in number; while, on the other hand, when the position A is passed, the contrary is the case. A current in one direction is therefore induced in each convolution during its passage from N to A, and another current in an opposite direction after that A has been passed. The same action takes place in the lower half of the ring; only here, as the lines of force cut the convolution from the opposite side, the effect is negative. Each convolution of the coil, therefore, as it revolves from B to A produces a current in one direction, which direction is reversed as the convolution passes from A to B. This is precisely the same effect as that produced by the change of polarity in the iron of the ring; the currents are moreover in the same direction, and the total effect is consequently their sum.

Such are the properties of the Gramme ring, the principles of which were first discovered in the year 1860 by Dr. Pacinotti, but which was brought to a perfect state and patented in 1870 by M. Gramme of Paris.

This beautiful invention is still of the greatest practical importance, as the principles involved in its construction are embodied in many of the most efficient of modern electric generators.

Another typical machine for the conversion of mechanical energy into electricity, is that which was invented in 1856 by Dr. Werner Siemens of Berlin. The armature or revolving part of this consists of a long soft-iron cylinder, which is free to revolve on a steel spindle which passes through it longitudinally. On each side of this cylinder and parallel to the spindle is cut a deep groove, in which is wound longitudinally over the ends of the cylinder a coil of insulated wire. The ends of the wire are connected with copper plates attached to but insulated from the spindle. Brass springs press against these and lead away the electric current induced in the wire when the armature is revolved in a magnetic field.

Fig. 5 shows the general arrangement of the machine. A is the armature, which revolves in a box formed by the soft-iron pole pieces B and C of the permanent magnet D. The energy required to revolve the armature is (through the inductive effect of the magnet on the coil) converted into an electric current, which leaves the coil by one of the brass springs and returns by the other. Several modern electric generators have armatures based upon this system.

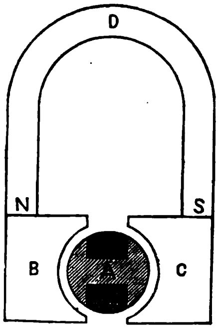

FIG. 5.
Siemens Machine.

Reverting now to fig. 2, we have seen that it is possible to produce a magnet by means of an electric current.

If a coil of insulated wire surround a soft-iron rod, the latter becomes magnetic as soon as an electric current is made to pass through the coil. It is, moreover, found that electro-magnets such as this are very much more powerful than those formed of magnetised steel. It is therefore usual to employ electro-magnets to produce the magnetic field necessary in a dynamo-electric generator. In the earlier forms of these

machines, batteries or other separate sources of electricity were used to produce the current for these magnets, but this is now, as a rule, unnecessary. In an electro-magnet, although the magnetism almost entirely ceases when the current is interrupted, yet an appreciable quantity remains. If, therefore, the armature coils of an electric generator be placed in the same circuit as the coils of the exciting magnets, the residual magnetism in the latter, although it may be very slight indeed to begin with, is sufficient to induce a certain amount of current in the armature, which in turn circulates round the magnet coils, and produces more magnetism. Thus, after a few revolutions of the armature, the magnets become magnetised to saturation, and the electric current arrives at its full strength.

This is the true principle of the dynamo-electric generator as compared with the magneto-electric machine; the current in the latter being induced by the revolution of an armature in the magnetic field of permanent magnets, while the former produces the magnetism required by means of the current induced by that magnetism in its own armature.

Having thus demonstrated how an electric current can be generated, we will pass on to see how light can be produced by means of such a current.

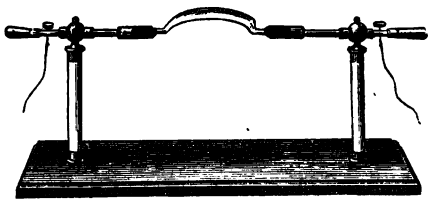

FIG. 6.—Sir Humphry Davy's Arc Lamp.

About the commencement of the present century, Sir Humphry Davy succeeded in producing at the Royal Institution the most brilliant light then known. By passing the current derived from an enormous galvanic battery of 4,000 plates through two charcoal points separated from one another, he obtained in air a continuous electric discharge, four inches in length, which was increased to seven inches when the experiment was repeated in vacuo. This discharge or arc, as it

was called, consisted of minute particles of the charcoal, which, being raised to white heat by the resistance offered to the current by the points, were conveyed across from one of these latter to the other, emitting during their passage a light of dazzling brilliancy.

The temperature of the electric arc has been variously estimated at from 2,000 to 6,000 degrees centigrade. In any case it is the most intense of all artificial sources of heat, for by its means Sir Humphry Davy succeeded in melting platinum, quartz, the sapphire, magnesia, lime, and other refractory substances, which till then had been considered altogether infusible.

The electric arc is still the most economical means by which electricity can be converted into light, and the modern form of an arc lamp differs from that employed by Davy only in the facts that gas carbon has been substituted for charcoal, as being more durable; and as the carbon is found to be gradually consumed, electro-magnetic appliances are made use of to maintain the points at a fixed distance from one another.

It is found in practice that the carbon that is connected with the positive pole of the generator burns away about twice as fast as the other. This is owing to the fact that the current detaches and carries away small particles of carbon from it, which it deposits upon the negative carbon. Owing to the same cause, the positive carbon takes a hollow form, while the extremity of the other remains pointed.

Sir Humphry Davy's arc lamp is illustrated in fig. 6.

FIG. 7.
The Electric Arc.

Another way of producing light by means of electricity is as follows. When an electric current of sufficient power is made to flow through some substance which offers a great resistance to its passage,

a large amount of heat is generated, and in certain cases the conductor becomes incandescent, or sufficiently heated to emit luminous rays. Thus, a strong current of electricity can bring a length of platinum wire to a white heat.

Many inventors have produced electric lamps based upon this fact, which is the principle of all the so-called incandescent lamps of the present day. One of the first of these was patented in 1845 by Augustus King. King's lamp was composed of a thin strip of graphite held between two metal clips, and attached to a porcelain rod, the whole being contained in a glass globe exhausted of air. The electric current was allowed to flow from end to end through the graphite, which was thus heated to incandescence.

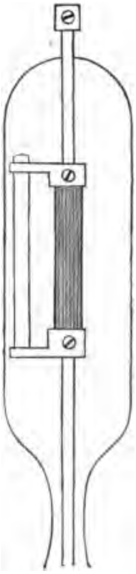

FIG. 8.—King's Incandescent Lamp.

It is thus possible to produce light from electricity in two ways; the current can either produce a discharge of white-hot particles of carbon between two electrodes formed of that substance, or else a strip of some such materials as carbon or platinum, offering a great resistance to the passage of electricity, can be rendered so hot as to become incandescent.

All modern electric lamps owe their light-giving power to either one of these principles, or else to the combined effect of the two together.

The principles that govern the generation of electric currents, and the manner in which light may be produced by their means, having been thus delineated, the truth of the following statement is obvious. An electric lighting installation must consist of four parts: firstly, there is the prime motor that produces the mechanical energy; secondly, the dynamo-electric machine that converts this energy into electricity; thirdly, the conductors that lead the currents so generated to where they are to be applied; and fourthly, the lamps by means of which the electricity is converted into light.

CHAPTER III.

ELECTRICAL, MECHANICAL, AND PHOTOMETRICAL MEASUREMENTS.

Electrical Measurements—The Volt—the Ohm—The Ampère—The Coulomb—The Farad—Ohm's Law—Galvanometers—The Ammeter—The Voltmeter—The Electro-dynamometer—Resistance Coils—Wheatstone's Bridge—The Lane-Fox Meter—Boys' Quantity Meter—The Edison Meter—Mechanical Units—The Horse-power—The Foot-pound—The Force de Cheval—The C.G.S. System of Units—The Dyne—The Erg—The Watt—The Joule—The Relations between Electricity and Work—The Watt Meter—The Erg Meter—Photometrical Units—The Standard Candle—The Carcel—Rumford's Photometer—Bunsen's Photometer.

THE employment of electric energy as a source of light has rendered necessary the adoption of certain units in terms of which electricity may be measured. So great was considered the importance of a universal system of electric measurements, that an International Congress of Electricians, held in Paris in 1881, devoted a large portion of the time at its disposal to the consideration of what would form a suitable series of standard units to be used alike in all countries.

The following are the units now generally adopted in practice.

The Volt is the name given to the unit of electromotive force or difference of potential; this name was given by the British Association in order to perpetuate the memory of the inventor of the voltaic battery, the Italian scientist Volta. The volt is a little less than (about 0·95 of) the difference of potential exhibited by the two poles or electrodes of a certain kind of galvanic cell called after its inventor the Daniell

Battery. Hence, to measure the electromotive force of an electric current, the latter should be compared with ninety-five hundredths of that of one Daniell cell.

The Ohm, called after the celebrated investigator into electric laws of the same name, is the unit of resistance.

All conductors offer a certain amount of resistance to the passage of electric currents, and in every case the resistance varies directly as the length and inversely as the cross section or thickness of the conductor. Moreover, since the areas of circles are proportional to the squares of their diameters, the resistance of conductors of circular cross section varies directly as their length and inversely as the squares of their diameter. The ohm is equal to the resistance of a column of mercury at a temperature of 0° centigrade, 1·05 metres (41·3393 inches) in length and 1 square millimetre (·03155 of a square inch) in cross section, to 48 metres (152·493 feet) of pure copper wire 1 millimetre (·03937 of an inch) in diameter, or about 100 yards of No. 8, Birmingham wire gauge, iron telegraph wire.

Subjoined is the resistance in ohms of a wire 1 foot long and one-thousandth of an inch in diameter of some of the more common of the metals.

	ohms
Silver annealed	9·151
,, hard drawn	9·936
Copper annealed	9·718
,, hard drawn	9·940
Gold annealed	12·52
,, hard drawn	12·74
Aluminium annealed	17·72
Zinc pressed	34·22
Platinum annealed	55·09
Iron annealed	59·10
Tin pressed	80·36
Lead pressed	119·39
Mercury liquid	578·6
German silver	127·32

Taking the resistance of a rod of silver of a certain size as equal to 1 ohm, a rod of equal bulk of gutta percha would offer a resistance equal to about 850,000,000,000,000,000,000 ohms.

The Ampère is the strength of current produced through a resistance of 1 ohm by an electromotive force of 1 volt. Thus if the combined resistance of an electric generator and the conductor connecting its poles be 1 ohm, and the electromotive force of the current produced by the generator 1 volt, the strength of the current circulating through the circuit, or the quantity of electricity that passes through any given point in that circuit in a second of time, will be one ampère. When an electric current is made to pass through water, the latter is decomposed into its constituent elements. An ampère is the strength of current capable of decomposing 1·4472 grains of water in a second of time.

The Coulomb is the unit of electric quantity, and is defined as the amount of electricity given by a current of the strength of one ampère in a second of time. The number of coulombs of current that pass through a conductor are, therefore, equal to the strength of the current in ampères multiplied by the number of seconds during which the current continues to flow.

The Farad is the unit of electric capacity. A body capable of containing one coulomb of current with an electromotive force of one volt has one farad of electric capacity. In other words, the unit of capacity equals the unit of quantity divided by the unit of electromotive force; the farad, therefore, equals the coulomb divided by the volt. The farad is named after Faraday, the illustrious discoverer of magneto-electricity.

The following formula is what is known as Ohm's law, and is of great importance, as it forms a connecting link between the resistance of a conductor and the electromotive force and strength of an electric current flowing in it:

Where C = the strength of current in ampères,
E = the electromotive force in volts,
R = the resistance in ohms,

$$C = \frac{E}{R} \text{ or } R = \frac{E}{C} \text{ or } E = C\,R.$$

Having thus described what are the units in terms of which

electricity is measured, we will now pass on to consider the manner in which a current can be compared to these units, and to describe the instruments employed for that purpose.

In Chapter II. it was shown that when an electric current was made to pass through a coil of wire in which was inclosed a balanced magnetic needle, the latter is deflected from the position of a parallel to the convolutions of the coil, the amount of the deflection being proportional to the strength of the current. On this principle are based most of the instruments for the measurement of the strength of electric currents. For very weak currents such as are used in telegraphy very delicate forms of galvanometers, as these instruments are called, have to be employed. This delicacy is obtained by employing coils of great length with many convolutions, while at the same time the magnetic needles require to be of little weight and must be free to turn on receiving the slightest impulse. The currents employed in electric lighting, however, are usually of considerable strength, and therefore for measuring them the galvanometers suitable for weak currents are comparatively useless. Hence special instruments are required. One of the best known of these is the tangent galvanometer, which is usually of the following construction: the coil consists of a single convolution from ten to fifteen inches in diameter of thick copper wire. In the centre of this ring-shaped coil is pivoted or suspended an exceedingly short magnetic needle. To use the instrument, it is first placed in such a position that by the directive force of the earth's magnetism the needle is parallel with the plane of the coil. It can then be proved that if a current be made to flow round the coil, the strength of that current is proportional to the tangent of the angle of deflection of the needle. That is to say that if the angle through which the needle is moved be measured, and the tangent of that angle taken, that tangent will be proportional to the strength of the current that caused the needle to be deflected. A graduated scale is usually fixed beneath the needle, so that the amount of deflection of the latter may be readily noted, and the strength of the current passing through the coil calculated.

Professors W. E. Ayrton and John Perry have recently patented a galvanometer especially designed for the measurement of electric currents of great strength. This instrument, which is called by its inventors the Ammeter, shows by means of a pointer in connection with a magnetic needle, the strength of a current in ampères. The coil, which is of few convolutions and made of wire of low resistance, acts upon a magnetic needle controlled in a direction irrespective of its position as regards the terrestrial poles by means of a permanent steel magnet of great power, the polar extremities of this magnet being so shaped as to render the angular deflection of the needle proportional to the strength of the current passing through the coil.

In the latest form of this instrument the coil is complex, being wound with a strand or cable composed of ten separate insulated wires. By means of a commutator or switch these wires can be connected together either in what is known as *series*, when the wires are all joined up end to end and form one long continuous circuit, or in *parallel circuits*, when each separate wire offers a distinct path to the current. In the former case the effect is that of a long coil of many convolutions and high resistance as suitable for the measurement of very small currents, while in the latter a coil of few convolutions and low resistance, designed for large currents, is obtained. Thus if, when the wires are connected in series, a current of 1 ampère produces a deflection of 5°, it will take 10 ampères to produce the same deflection when the wires are in parallel circuits.

Fig. 9 represents one of Perry and Ayrton's commutator Ammeters as manufactured by Messrs. Paterson and Cooper.

Electromotive force can be measured in several different ways, only one of which, however, is generally employed in electric lighting. It is found that by employing a galvanometer fitted with a coil having a very high resistance, the electromotive force of a current can be measured in volts in very much the same manner as its strength in ampères. Professors Perry and Ayrton have, therefore, produced an instrument called a voltmeter, which measures the electromotive force of electric

currents in volts, and which is based upon exactly the same principles as their ammeter. The coil of the voltmeter has, however, a resistance about 1,300 times greater than that of the ammeter.

Another instrument for measuring electric currents is Siemens' electro-dynamometer. It consists of a wooden frame supporting a fixed coil of insulated wire, around which is suspended by a fine spiral spring a second coil. The two coils are placed so as to be normally at right angles to one another; and when the current to be measured is passed through both of them, the movable coil is deflected towards parallelism

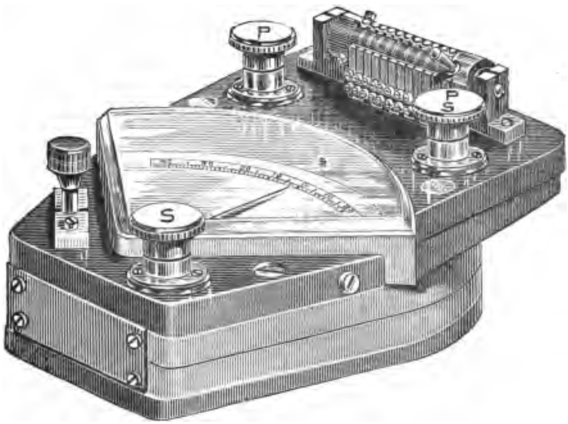

FIG. 9.—The Ammeter.

with the other. By means of an index needle and scale at the top of the instrument, the force with which the movable coil is deflected can be measured; and by referring to a set of tables supplied with each instrument, the strength of the current is found.

Since the deflection of the movable coil is due to an attractive action between the currents in the two coils, the effect is exactly the same whether the current being measured is continuous or alternating in direction. This gives the instrument a decided advantage over those in which a magnetic

needle is employed, and with which alternating currents cannot be measured.

The resistance of any conductor is usually obtained by comparing it with some other known resistance. Standard resistances in the form of coils of German silver wire, which does not alter its resistance to any extent with changes in temperature, are generally employed. They are contained in boxes, and are so arranged that by means of switches any

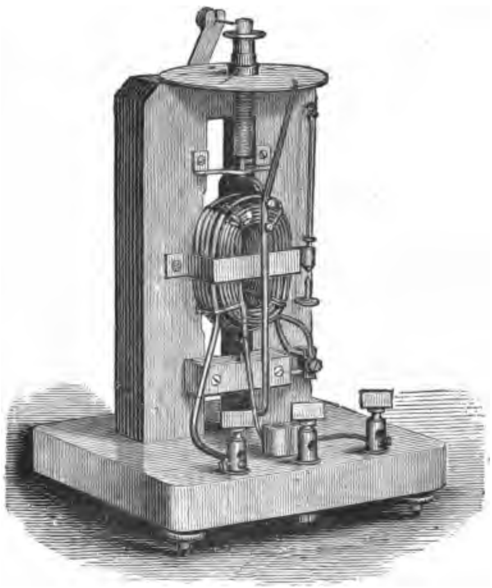

FIG. 10.—Siemens' Electro-Dynamometer.

number can be connected together in series so as to form one continuous conductor.

If the resistance of each coil be equal to one ohm, with a sufficient number of coils a resistance equal to any number of ohms can be obtained. As the expense of a large number of such coils would be very great, in practice the successive coils are usually made of the following resistances: 1, 2, 2, 5, 10, 20, 20, 50, 100, 200, 500, up to 10,000 ohms.

By switching certain of these coils into circuit, any desired number up to 22,000 ohms can be readily obtained.

With a set of resistance coils, the resistance of any given conductor can be obtained by the following means: The conductor is first placed in circuit with a sensitive galvanometer and a galvanic battery supplying a constant current, and the deflection of the galvanometer needle noted. The same battery and galvanometer are next connected in the same way with a set of resistance coils, and a sufficient number of the latter switched into circuit to produce a deflection exactly equal to that which took place when the conductor was in circuit instead of the resistance coils. The number of ohms in the

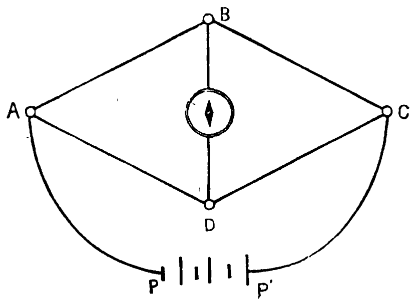

FIG. 11.—The Wheatstone Bridge.

shape of resistance coils requisite to produce this amount of deflection is clearly equal to the resistance of the conductor.

The ordinary method for measuring resistance, is to employ an instrument known as Wheatstone's Bridge, which is dependent upon the following principle.

When the positive and negative poles of an electric generator are connected together by a conductor of uniform resistance throughout its entire length, it is found that the potential of the electric current decreases at a uniform rate from the positive to the negative pole. Again, with a conductor parts of which are of higher resistance than the remainder, the fall of potential is most rapid where the resistance is greatest. From this we obtain the general law, that the fall of potential between any

two points in a circuit is directly proportional to the resistance between these points.

The Wheatstone Bridge may be described as follows. Conceive an arrangement of four conductors in the form of a lozenge-shaped figure A B C D (fig. 11), of which A B and C D are opposite sides. Now, let A and C—opposite corners of the figure—be connected to P and P′, the positive and negative poles of an electric generator, and the positive current will flow from A to C, partly by A B C, and partly by A D C. Now, the current reaches A with a certain definite potential, this potential falling from A to B and B to C, and also from A to D and D to C. Then, according to the law of the fall of potential, in order that the potential of B shall be equal to that of D, the following relation must exist among the resistances of the four arms:

$$AB : BC :: AD : DC.$$

In using the instrument, a galvanometer is inserted in a circuit from B to D, so that any difference in the potential of B and D is immediately shown by a deflection of the galvanometer needle, due to the current set up from the high to the low potential. The conductor to be tested is next made to form one of the arms, while the other three are made up of resistance coils until the resistances of all four are balanced, and the galvanometer shows no deflection. Then by a simple calculation the value of the unknown resistance is arrived at, according to the proportion given above.

The measurement of electric quantity is effected by means of what are known as integrating instruments, which keep a continuous record of the strength of the current, or by means of instruments dependent upon the chemical effects of electricity.

The Lane-Fox meter comes under the former category. It consists of an electro-magnet in circuit with the main current, which controls the position on a shaft of the driving wheel of a mechanical counter. This driving wheel, which is free to slide up and down on a vertical shaft, gears with a conical boxwood roller fixed on a shaft parallel with the shaft of the driving wheel, and which is rotated at a constant speed by a small electro-magnetic motor worked by the current. Now, when

the current is strong, and the electro-magnet consequently powerfully excited, the driving wheel of the counter is lifted to the upper end of its shaft, so that it gears with that part of the conical boxwood roller which is of large diameter. The motion communicated by the motor to the pointers of the counter is therefore rapid, and the latter therefore revolve through a large angle in a given time. When, however, on the contrary, the current passing round the electro-magnet is weak, the latter is unable to lift the driving wheel, which therefore remains low down upon its shaft, and gears with the small end of the boxwood roller. The motion, therefore, imparted to the pointers of the counter is proportionately slow. It is evident that if the conical roller be made of the proper shape, the motion transmitted to the counter by the electro-motor will be proportional to the power of the electro-magnet, and consequently to the strength of the current. If, then, the dials of the counter be suitably graduated, the pointers may be made to indicate in coulombs the amount of electricity that passes through the meter.

Boys' quantity meter is based upon the two following principles :

1. An electro-magnet acts upon its armature with a force proportional to the square of the current.

2. The square of the number of vibrations of a pendulum is a measure of the force which controls its action.

Mr. Boys employs a vertical rocking shaft, to which are attached two soft iron armatures and two long weighted arms. The rocking shaft is maintained in a constant state of vibration by an electro-magnet, which, whenever the vibrations fall below a certain limit, receives a portion of the electric current, and thus gives a renewed impulse to one of the armatures by attracting it.

In connection with the second armature is another electromagnet, through the coils of which circulates constantly a certain definite fraction of the current to be measured. As the rocking shaft vibrates, the armature moves between the poles of the magnet, the controlling force of which is, by the principle given above, proportional to the square of the current. But

the square of the rate of the vibration of the rocking shaft is a measure of the controlling force, hence the rate of vibration is a measure of the strength of the current.

In connection with the rocking shaft is an escapement, and a set of wheels and counters, the latter of which register the number of vibrations, and consequently the quantity of current that passes through the meter. As this quantity bears a fixed relation to the main current, the quantity of the latter can be calculated.

Another form of quantity meter, and one that has been adopted by Mr. Edison in his system of electric lighting, is based upon the chemical effects of an electric current. When

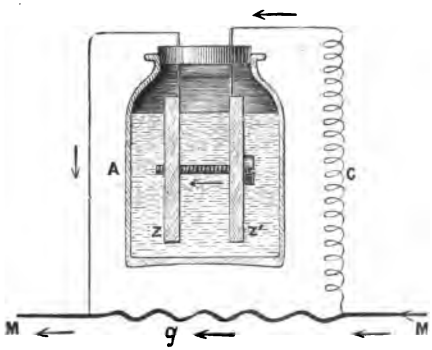

FIG. 12.—The Edison Quantity Meter.

two plates of zinc immersed in a solution of sulphate of zinc are connected with the poles of an electric generator, it is found that one of the plates is gradually dissolved, while metallic zinc is deposited upon the surface of the other. Now, it can be experimentally proved that the increase in weight of the latter zinc plate is proportional to the quantity of electricity that has passed through the solution during the time in which the increase took place. Fig. 12, which represents one of the Edison meters, is an arrangement such as has been described. As it would not do, however, to allow the full strength of such a current as is employed for electric lighting to pass in its

entirely through the meter, the latter is placed in what is called a shunt circuit with the main conductor ; that is to say, instead of being made to form a part of the latter, it forms a parallel circuit through which part of the main current is able to flow. Now, when an electric current has two circuits or paths through which it can flow, it flows through them inversely as the resistance of each. That is to say, that if one of the circuits has a resistance of one, the other of two ohms, twice as much current will flow through the first as through the second. In the figure, M M is the main conductor, the arrows showing the direction of the current. The resistances of the main conductor, or rather of that portion of it between the junctions of the branch wires leading to the meter, and of the meter and its leading wires, are so arranged, that of the current arriving through the main conductor, $\frac{1}{870}$ of the electricity is diverted and flows through the zinc plates Z and Z′, and the sulphate of zinc solution between them. As, however, the resistance of this liquid diminishes with an increase in its temperature, and since it is almost impossible to keep the temperature always uniform, the proportion of current passing through the meter would not always be maintained the same. In order to obviate this difficulty, the coil of copper wire C is introduced into the shunt circuit. Now, the resistance of the copper increases with a rise of temperature, and thus counteracts the opposite tendency of the sulphate of zinc solution. Hence exactly $\frac{1}{870}$ of the current that arrives passes through the meter, while the remaining $\frac{869}{870}$ of the electricity flows directly from M to M. Under the action of the former portion, the zinc plate Z′ decreases, and Z increases in weight, the increase in the weight of the latter being exactly proportional to the current that passes through the meter. By weighing this plate from time to time the current that has passed through the meter can readily be estimated, and as this will always be $\frac{1}{870}$ of the total current, the latter can easily be obtained in terms of the ampère per second or the coulomb.

In a more elaborate meter based upon the same principle, Mr. Edison employs two copper cylinders attached by links to the extremities of a balanced beam, and dipping into two

vessels of sulphate of copper solution, each containing another copper cylinder of larger diameter. The electric current is alternately passed through the two cylinders of each cell in opposite directions. Thus, when in one cell the current is flowing from the fixed cylinder to the one suspended from the extremity of the beam, in the other cell it is passing from the cylinder that is suspended to the one that is fixed. Now, these copper cylinders, immersed in a solution of copper sulphate, are acted upon by the electricity in precisely the same manner as are the zinc plates in the more simple form of Edison meter previously described. Therefore, when in one cell the current is flowing from the fixed cylinder to the one that is attached to the beam, the latter is constantly having metallic copper deposited upon it, and is at every instant gaining in weight. In the other cell, on the contrary, since the current is in the opposite direction, it is the fixed cylinder that is becoming heavier, and the suspended cylinder is at every instant losing weight. Hence, as the cylinder suspended from one extremity of the beam is becoming gradually heavier, and the one at the other extremity lighter, a time will come when the balance of the beam will be destroyed, its inertia overcome, and its horizontal position altered. At this stage, therefore, the beam is depressed at one extremity, and elevated at the other. As soon, however, as it has tilted to a certain angle, an electro-magnet comes into operation, which reverses the direction of the electric current in each of the cells. In consequence of this, the heavy cylinder now commences to lighten, while the light one becomes heavier. When this action has proceeded for a sufficient time the beam is again tilted, only in a direction opposite to that in which it moved in the first instance. When a certain inclination is reached, the electro-magnet again acts upon the direction of the current in the cells, and the whole operation is repeated. In this way an alternate oscillating motion is set up, which continues as long as an electric current passes through the meter, and the rapidity of which is proportional to the strength of the current. Connected with the beam is a mechanical counter, the unit pointer of which advances through a certain angle at every oscillation. Each

oscillation, however, represents a certain amount of copper deposited, which in turn is the result of the action of a certain quantity of electricity. Hence the pointers of the counter register the quantity of electric current that passes through the meter.

As the currents employed for electric lighting are usually obtained by the exertion of mechanical power, the units adopted by engineers for the measurement of the latter are not without their interest to the employers of electricity.

The Horse-power, often written simply H.P., is the English unit of power. One horse-power equals the force capable of raising a weight of 33,000 pounds through a distance of one foot in one minute of time. The work done in raising a weight of one pound through a distance of one foot is the unit of work and is called a *foot-pound.* A horse-power is, therefore, equal to 33,000 foot-pounds per minute, 550 foot-pounds per second, or 1,980,000 foot-pounds per hour. The horse-power is the unit of power commonly employed in this country; there are, however, several others.

The Force de Cheval, or the *Cheval Vapeur*, is the French unit, and equals the power requisite to raise a weight of 75 kilogrammes through a distance of one meter in one second. A cheval vapeur equals $542\frac{1}{2}$ foot-pounds per second, or nearly ·9863 of an English horse-power. One horse-power, therefore, is equal to 1·0139 of a cheval vapeur.

As stated above, the English unit of work is the foot-pound; the corresponding French unit is the kilogrammetre, or the work done in raising a weight equal to a kilogramme through the distance of one metre.

Another system of units, devised by a committee of the British Association, is based on the fundamental units of space, mass, and time, the centimetre, the gramme, and the second. From the initial letters of these three units the system has been called the C.G.S. system. The following are the units employed:

The Dyne is the unit of force, and is 'that force which acting on a gramme of matter for a second of time generates a velocity of one centimetre per second.'

The Erg is the unit of work, and represents the work done in moving a body through the distance of one centimetre against a force of one dyne. The erg is, therefore, equal to the dyne multiplied by the centimetre. A kilogrammetre equals 98,100,000 ergs.

The Watt is the unit of energy, and is equal to 10,000,000 ergs per second. The energy of an electric current in watts is equal to the strength of the current in ampères multiplied by its electromotive force in volts. One horse-power equals 746 watts.

As in both the electrical and mechanical systems of units, the units adopted have in many cases been found too large or too small for practical use, the prefixes *meg*, to represent one million times, *micro*, to represent the one-millionth part, and *milli*, the one-thousandth part, are often used.

The Joule is the unit of heat, and is the amount of heat required to raise the temperature of one gramme of water one degree centigrade.

The following table will give in a clear form the relation between the various units of electricity and work :

A current of one ampère with an electromotive force of one volt flowing during one hour	=	one watt hour.
		10,000,000 erg hours.
		2,645 foot-pounds.
		366·84 kilogrammetres.
		·00135 force-de-cheval heures.
		·00134 horse-power hours.
		3,600 joules.
		3,600 volt-coulombs.

Messrs. Siemens have brought out an energy meter, which measures the energy of an electric current passing through a conductor, in watts. The instrument is called the Watt meter, and is constructed and used in much the same manner as the Siemens dynamometer. The main current passes through only one coil, however; and the other, which is made of fine German silver wire, is placed in a shunt circuit so as to draw off only a small proportion of the current.

A self-registering energy meter has been invented by Professors Perry and Ayrton, and is called the erg meter. It con-

sists of a clock with a pendulum escapement. The current, the energy of which is to be measured, passes through a coil of wire in the vicinity of the pendulum, which carries a second coil of fine wire in a slant circuit. By this arrangement the rate at which the hands of the clock move is retarded to an extent proportional to the energy of the current that passes through the meter during a given time. If, then, the amount of retardation be noted, the energy of the current can be accurately determined.

Photometrical Units.

The English unit of light is the luminous intensity derived from a standard candle burning 120 grains of spermaceti per hour. When, therefore, a light of one candle is spoken of, a light equal in intensity to that given by one of these standard candles is implied.

In France the standard measure is the carcel, which is the luminous intensity of the flame of a standard carcel lamp burning 648 grains of pure oil per hour. The carcel equals about 9·5 English candles.

The instruments employed for comparing the light given by electric lamps or other sources of illumination with the standard candle or carcel, are called photometers. The photometer invented by Count Rumford is one of the simplest of these instruments. An opaque rod about the diameter of an ordinary lead pencil is fixed vertically in front of a white paper screen. The lamp to be measured and the standard candle or carcel are placed in such positions relatively to the opaque rod, that each throws a distinct shadow of the latter upon the surface of the screen, and at the same time illuminates the shadow thrown by the other. One of the lights is then moved towards or away from the screen until the two shadows become of equal depth. Then, according to the law that 'the amount of illumination diminishes in proportion to the square of the distance of the source of illumination,' the brilliancy of the two lights is as the square of their distances from the screen. Thus, if with a given lamp and a standard candle the former has to be placed at a distance of ten feet from the screen when

the latter is one foot distant in order that the shadows cast by each shall be exactly equal in depth, the light emitted by the lamp is equal to 100 standard candles, or the lamp itself is of 100-candle power.

Rumford's photometer is valuable chiefly because of its simplicity, and because of the rapidity with which it can be manipulated. When, however, great accuracy is required, it is not found sufficiently sensitive. In the latter case Bunsen's photometer may be used. This instrument is in principle based upon the fact that a semi-transparent grease spot situated on a paper screen is invisible when the screen is equally illuminated on both sides. The photometer consists of a horizontal beam which is graduated from end to end. At one extremity of this beam is placed a standard candle or a carcel lamp, while at the other end is the source of light to be measured. On the beam slides a carriage, attached vertically to which is a paper disc, in the centre of which is a semi-transparent spot resulting from the application of a small quantity of a solution of spermaceti in benzoline. When measuring, the carriage is moved on the beam to such a position that the spot becomes invisible, owing to the fact that the light received on each side of the disc from the candle and the source of light to be measured respectively is equal. The distance of the disc from each of these is then noted by means of the graduated scale, and the squares of these distances give the relative intensities of the two sources of light.

This instrument is very much more sensitive than the Rumford photometer, in that it is always quite easy to see whether the grease spot is visible or not, while in the other instrument it is often impossible, owing to the difference in the colour of the light obtained from the standard candle and the lamp to be measured, to determine when the two shadows thrown on the screen are exactly equal in depth. For this reason Bunsen's photometer is the one generally employed in connection with electric lighting.

CHAPTER IV.

SOURCES OF POWER.

Steam Engines—Compound Condensing Engines—Compound Non-condensing Engines—Corliss Engines—Semi-portable Engines—Three-Cylinder and Rotary Engines—Choice of Engines—Governors—Coupled Engines—Gas Engines—Advantages of Gas Engines—Economic Gas—Caloric Engines—Water Power—Water Wheels and Turbines.

In Chapter II. it was stated that electric currents for lighting purposes are usually generated in conducting circuits by the employment of mechanical energy, the latter being expended in causing an armature with a coil of wire forming part of the circuit to revolve in a magnetic field in such a manner as to cut the lines of magnetic force. In an electric lighting installation, therefore, one of the chief parts of the system must necessarily be the prime mover from which the energy required to work the dynamo-electric machine is obtained.

There are several different ways in which mechanical energy suitable for driving electric lighting machinery can be generated. First of all there is the steam engine, which, from its economy and general adaptability, has been more largely employed as yet than any other form of motor. Secondly, we have the gas engine, which, though not so economical in working as the steam engine, requires less attention, and is adapted for small installations. Thirdly, there is the hot-air or caloric engine, which has not as yet, however, been much employed, although when a small amount of power only is required, it has several of the advantages of the gas engine, without the necessity of a supply of gas. Fourthly and lastly, we come to water power as obtained from wheels and turbines, which, when available,

is certainly the most economical and the most convenient source of power existent.

There is more than one form of steam engine suitable for electric lighting, the best form for any particular installation being dependent upon local circumstances. Thus, for large installations in localities where the price of coal is high, compound condensing engines, which are very economical of fuel, are advisable. On the other hand, where coal is cheap, non-condensing engines are more suitable, since their first cost and the expenses connected with their maintenance are less. Again, for small installations, where only little power is wanted, engines of a totally different class are to be preferred.

Compound high and low pressure condensing engines are, as regards fuel, the most economical of all steam engines. Owing, however, to their somewhat complicated nature, their first cost is necessarily somewhat high, their cost of maintenance considerable, and the amount of space they take up large. Powerful engines of this class consume from 1·8 to 2·3 lbs. of coal per horse-power per hour.

Compound high and low pressure non-condensing engines come next in point of economy of fuel. The average in their case is about 2·7 lbs. of coal per horse-power per hour for engines of from 200 to 300 horse-power.

Of non-compound engines, the 'Corliss' is perhaps the best known, the peculiar valve motion of this engine producing great economy in steam. With Corliss engines of from 150 to 200 gross horse-power the amount of coal consumed per horse-power per hour is from 2·8 to 3·6 lbs.

Small steam engines as a rule are less economical in the fuel consumed for every horse-power than are those of large dimensions. Hence it is usually more economical to employ one large engine than several smaller ones. With some of the modern semi-portable engines, however, wonderfully economical results have been obtained. Thus in a trial of a compound engine of 12 nominal horse-power built by Messrs. Ruston, Proctor & Co., of Lincoln, an effective power of over 29 horse-power was developed with the very small expenditure of only 2·54 lbs. of coal per horse-power per hour. Such a

remarkable result must, however, be taken as phenomenal for engines of this size, for from 2·7 to 4 lbs. of coal per horse-power per hour is usually required.

Other forms of steam engines are the 'three-cylinder' and the 'rotary' types. Both of these have been considerably used in electric lighting installations on board ship, where they are advantageous on account of the small amount of space that they require.

Rotary engines have also the advantage of producing a direct rotary motion without the intervention of cranks and connecting rods; they can, moreover, be run at the great speed of over 1,000 revolutions per minute with little friction and great regularity.

In choosing between the various forms of steam engines, the following are the chief considerations to be taken into account:

1. The horse-power required.
2. The space available for engine and boilers.
3. The price of coals in the district.
4. The cost of attendance.

When the power required is very considerable, the available space large, and the price of coals high, it will in most cases be best to employ compound condensing engines with double-flued Lancashire or multitubular boilers, mechanical stoking arrangements for the boilers being also advantageous.

Where the price of coal is more moderate, non-condensing engines of the same type are to be preferred, as the condenser adds very considerably to the prime and working expenses.

Again, where coal is cheap, as it generally is in the neighbourhood of coal pits, simple engines of the Corliss or other similar type are all that can be desired.

For small installations, such as are wanted for small towns and villages, country mansions, manufactories, &c., where the power required does not exceed 100 horse-power, the semi-fixed or semi-portable form of engine is perhaps the best. In these engines the working parts are placed beneath the boiler, which is of the locomotive multitubular pattern, the whole being attached to one bed-plate so as to be complete in

itself. The cost of fixing is thus very slight, no tall brick chimney being required, and very little other masonry work necessary. Engines of this class are manufactured both simple and compound, run very steadily, are economical of fuel, require little attendance, and take up a small amount of space.

The 'Robey' electric light engine and locomotive boiler combined is specially designed for providing economical steam power in a small space. The boiler is connected to the engine by being bolted to the cylinder only, and carried by rollers working in grooves at the fire-box end, thus relieving the boiler of all strain. The base-plate is formed at one end into an ash-pit with damper-doors, and is made suitable for receiving the fire-box end of the boiler, the other end of which is carried by a crutch-shaped casting fixed over the cylinders. The end of the base-plate under the cylinders forms a feed-water heater tank, into which the cylinder cocks discharge all condensed water, and into which a portion of the exhaust steam is so directed as to heat the feed-water to nearly boiling point before going into the boiler. The whole of the parts of both engine and boiler being included on one foundation or base-plate, heavy and expensive masonry foundations are dispensed with, the weight of the boiler and its contained water acting as an extra weight to assist in keeping the whole machinery in rigid position. The engine is fitted with improved expansion gear and patent equilibrium governors, whereby the greatest steadiness in working is secured.

The steam engines employed for electric lighting should be fitted with a sensitive governor, so that the speed may be maintained as uniform as possible. Steam-engine governors usually consist of two metal balls, which are fixed at the extremities of two movable arms connected with a shaft rotated by the engine. When the speed increases the balls are thrown outwards by the action of centrifugal force, and a lever is thereby actuated which can be made to correct the speed of the engine in different ways. It can be connected with a throttle valve in the steam pipe, so that when the governor balls fly apart the pressure of the steam that enters the cylinders is reduced. Again, as is the case in the Corliss engine, the

governor may determine the point at which the steam entering the cylinders is cut off, thus producing more or less expansion. In other engines the governor, by altering the position of a link, regulates the travel of what is known as an expansion slide, which allows the steam to expand more or less in the cylinders, thus regulating the speed. High-speed governors are usually best.

The evident fault of all steam governors is that they cannot begin to act until a perceptible change in the speed of the engine has actually taken place; in fact, they are not a remedy against the occurrence of speed variation, but only a cure for it after that it has occurred. If sufficiently sensitive, however, the amount of variation allowed by a governor will be very slight.

Engines for electric lighting should run as steadily as possible, and should therefore be fitted with heavy fly-wheels, which, as accumulators of developed power, tend to overcome inequalities of motion. Coupled engines, that is to say, a pair of engines working on one shaft, are found to run more steadily than single ones, since if the cranks are placed at right angles to one another, one engine is in the middle when the other is at the end of the stroke. It is often advisable to employ a pair of coupled engines each running at half its full power. With such an arrangement, should anything go wrong with either engine, the two can be disconnected, and the faulty engine stopped, when the other will be capable of doing the whole work. In this way the probability of a total breakdown is very much lessened.

Gas Engines.

In towns and in other places where gas is readily obtainable, a gas engine is a very convenient form of motor. Gas engines take very little space, require little attention, and are fairly economical. There are no boilers necessary, with their consequent fires, coal, smoke, and ashes. The moment the gas is turned on the engine is ready to start, and when the engine is not required the turning off of the gas immediately stops it.

Gas engines are dependent for their power on the explosive

nature of a mixture of ordinary coal gas and atmospheric air. The usual proportion is eight volumes of air to one of gas. This explosive mixture is admitted into a closed cylinder, where part of it is ignited; the consequent explosion serves to expand the remainder, and a piston, connecting rod, and crank are thereby actuated as in a steam engine. The chief difficulty with gas engines when employed for generating electricity is want of steadiness, each explosion producing a distinct pulsation in the speed. This can only be obviated by the employment of very heavy fly-wheels either on the engine or dynamo shaft. Engines in which the gas is exploded at each revolution of the crank, are more regular in their working than those which make two or more revolutions for every impulse.

Gas engines require from twenty to twenty-five cubic feet of gas per horse-power per hour.

It is by no means necessary that the gas employed in gas engines should be of the extreme purity required for direct illuminating purposes. There are several systems for producing gas, which are very much more economical than the one generally employed. The gas is certainly by no means pure, and would never do for illumination, but when used to work a gas engine it is quite as effective as purer gas generated in a more expensive fashion. It is believed that with large gas engines and economic gas generators, a smaller amount of fuel is required per horse-power than is the case with steam engines.

Caloric Engines.

Caloric or hot-air engines have not as yet been much employed for electric lighting. There does not seem, however, to be any reason why they should not be of considerable use. They have most of the advantages of gas engines, and can take the place of the latter when gas cannot be obtained. In caloric engines the motive power is atmospheric air, which, after having been forced into a closed retort by means of a pump, is expanded through the agency of heat. A pressure of air is thus obtained which works, after the manner of steam, an engine similar in principle to a steam engine. The

advantages of this engine are that pressure can be got up in a very short time, the engine is of small dimensions, and the exhaust air is free from smoke, and invisible.

Water Power.

Where water power can be obtained in sufficient quantity, there is no need for steam or other artificial sources of energy. In many localities there are rivers containing power sufficient for all purposes. In determining whether a fall of water is suitable and sufficient for driving electric machinery, the following are the chief considerations to be taken into account:

1. The head of water obtainable; that is to say, the height from the source to the bottom of the fall.
2. The quantity of water obtainable.
3. Whether the head or quantity is liable to alteration owing to floods or other causes.

The greater the head and the quantity of the water, the greater will be the power at command. When the head or quantity is liable to vary greatly, special precautions must be taken in order to obtain a constant amount of power.

Either water-wheels or turbines can be employed to utilise the force of the water, and after the first cost the annual expenses are very small, as the cost of repairs, supervision, and lubrication are the only items.

The following is a formula given by Molesworth for the calculation of water-power:

THE THEORETICAL POWER OF WATER.

Where Q = quantity of water in cubic feet per minute,
h = head of water from the tail-race in feet,
P = theoretical horse-power,

$$P = \cdot 001892\,Qh$$
$$Q = \frac{528\cdot 5\,P}{h}.$$

EFFECTIVE HORSE-POWER FOR DIFFERENT MOTORS.

Theoretical horse-power	= 1·00
Undershot water-wheel	= ·35
Poncelet's water-wheel	= ·60
Breast water-wheel	= ·55
High breast water-wheel	= ·60
Overshot water-wheel	= ·68
Turbine	= ·70

To estimate the effective power of a fall of water, its theoretical horse-power should be first obtained, and that multiplied by the efficiency of the kind of motor to be employed.

CHAPTER V.

DYNAMO-ELECTRIC GENERATORS.

The Field Magnets—Armatures—Dynamos of Gramme, Siemens, Edison, Edison-Hopkinson, Brush, Schuckert, Gülcher, Bürgin, Elphinstone-Vincent, Gordon, Lumley, Ferranti-Thompson, Hopkinson and Muirhead, Maxim—Future Progress in Dynamos.

THE action of dynamo-electric generators as employed to produce the currents required for electric lighting is due to the following discovery made by Faraday.

When a conductor forming an electric circuit is moved in a magnetic field so as to cut the lines of magnetic force in increasing or decreasing ratio, an electric current is induced in the conductor, which lasts so long as the motion continues, and the direction of which is governed one way or the other, according to whether the number of lines of force that are being cut by the conductor is increasing or decreasing at every instant. In other words, when a wire is moved in certain directions in proximity to the poles of a magnet, an electric current due to the combined effect of the motion and the inductive effect of the magnet flows through the wire. Dynamo-electric generators are simply machines in which this inductive effect of a magnet on a moving wire is so regulated as to obtain a maximum of electric current with the least possible expenditure of mechanical force. Every dynamo, as for brevity dynamo-electric generators are usually called, consists of two principal parts: the field magnets, that produce the magnetic field with its lines of magnetic force; and the armature, which revolves in that field in such a manner that the coils of wire of which it is formed cut the lines of force so that an electric current is induced within them. Modern dynamos differ from one another as regards the strength and electro-

motive force of the currents that they generate, the dimensions, form, and general arrangement of their field magnets, the construction of the armature, and the manner in which the circuit is arranged. Continuous current machines are those which generate currents constantly in one direction; while alternating machines produce currents the direction of which is reversed at frequent intervals.

The field magnets of a dynamo can be excited in several different ways. In fig. 13 we have a machine with the arma-

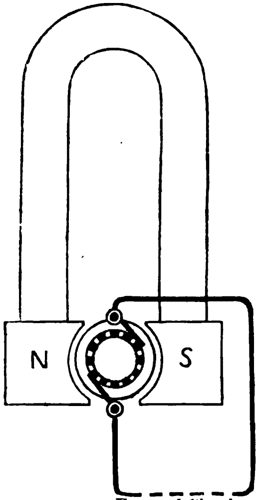

FIG. 13.—Dynamo with Permanent Magnets.

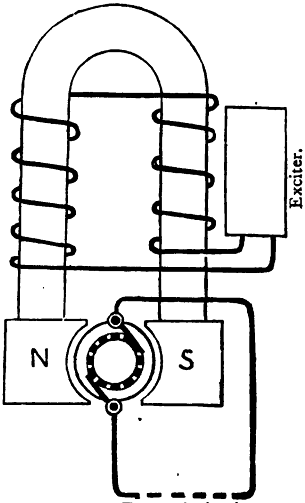

FIG. 14.—Dynamo with separate Exciter.

ture revolving between the pole pieces N and S of a permanent steel magnet. In most of the older forms of electric generators these permanent magnets were the rule; they have, however, been abandoned by modern electricians in favour of electro-magnets, which are more easily obtained of sufficient power.

We have already seen that when a current of electricity is made to flow through a conducting wire which is wound on a soft-iron bar, the latter becomes magnetised and remains in a magnetic state so long as the current continues to flow through the wire. Fig. 14 is a diagram of a dynamo constructed with

an electro-magnet, the current required to excite the latter being obtained from a separate electric generator, such as a battery or another dynamo.

In fig. 15 we have a machine in which the magnet coils are in the same circuit as the armature. In this arrangement, which is called a series dynamo, the residuary magnetism retained by the iron of the magnets—iron, however soft, after having been once magnetised always retains a certain amount of magnetism—is sufficient to start a very weak current when the armature is rotated. Since, however, this current circulates through the magnet coils, the magnetism of the iron is immediately increased. This increase in the strength of the magnets calls up a stronger current in the armature, which again goes to still further strengthen the inducing influence. In this manner, after the machine has once been set in motion, the current generated and the strength of the magnets go on increasing until the iron of the latter is magnetised to saturation, that is to say, magnetised as strongly as is possible. Thus, after the armature has made a few revolutions, the current obtained is of full strength. A machine on this principle is called a self-exciting series dynamo, for the magnets are themselves excited by the currents that they induce in the armature, and the coils of the magnet and armature are joined so as to form one continuous circuit, that is, they are what is technically termed joined in series.

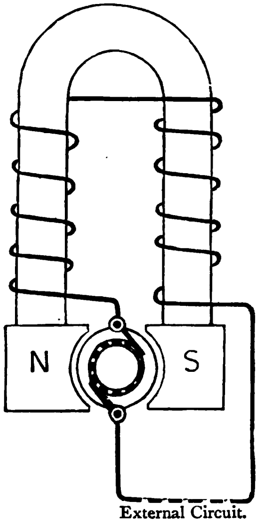

FIG. 15.—Series Dynamo.

Another form of self-exciting machine is known as the shunt dynamo. In this arrangement, which is illustrated in fig. 16, the magnet coils are placed in what is called a shunt or derived circuit. When an electric current has two paths or

conductors through which it can flow, it passes through each inversely as its resistance. In a shunt dynamo, the magnet coils are so connected as to form a kind of bridge or short circuit between the two ends of the armature wire. The current generated in the latter has thus two paths by which it can travel. It can pass through both the main working circuit and the electric lamps, and also through the wire forming the magnet coils. In practical working the latter are made to bear such relation as regards resistance to the main circuit that only sufficient current passes through them to excite the magnets to saturation. In this manner the electricity

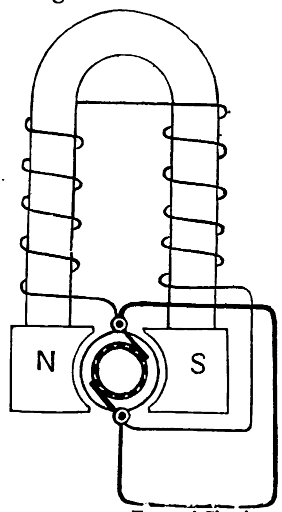

FIG. 16.—Shunt Dynamo.

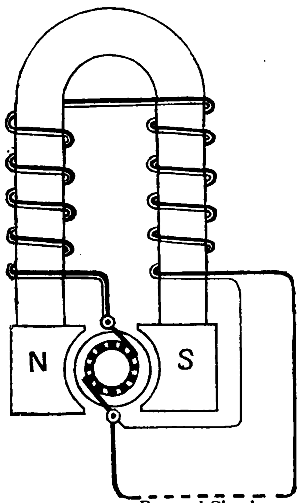

FIG. 17.—Compound Shunt and Series Dynamo.

generated by the machine is divided ; part goes through the shunt circuit and magnetises the magnets, while the rest flows through the main conductor and the electric lamps. The fifth and last way in which the field magnets of a dynamo can be excited, is in reality a combination of the shunt and the series methods. The magnets are wound with two distinct wires, one of which is placed in series with the armature, while

the other is made to form a shunt circuit. This arrangement is shown in fig. 17.

The advantages of each of these various modes of connection, and the special purposes for which they are employed, will be found explained later on in the chapter devoted to electric systems.

The armatures employed in continuous current dynamos may be divided into two distinct classes, which differ from one another fundamentally. The first class comprises all armatures of the type based upon the principles of the Gramme ring ; the second class may be termed the drum-shaped type, and consists of those armatures which, like the Siemens, are formed of coils of conducting wire wound longitudinally on a cylinder.

Machines designed with a view of producing currents of low electromotive force are provided with armatures, the wire of which is short in length and of large cross-section ; while when currents of high electromotive force are required, the armature is wound with a large quantity of small wire. The reason for this is clear. The larger the cross-section of the wire and the shorter it is, the less is the total internal resistance of the armature. Now, since the strength of the current produced is equal to the electromotive force divided by the resistance, if the current is the same, and the resistance is small, the electromotive force must necessarily be low. On the other hand, when the armature contains many convolutions of small wire the resistance is great ; but since the electromotive force of the current is proportional to the difference of potential at the two ends of the armature wire, and since this difference of potential is increased when there are many convolutions and decreased when there are few, the electromotive force of the current generated is high when the armature is wound with a long wire forming many convolutions, and low when the length of the wire and the number of convolutions are small. In this manner, with suitably wound armatures, it is possible to obtain currents of high or low electromotive force.

We will now proceed to a more detailed description of the principal of modern dynamo-electric generators.

The Gramme Machine.

The Gramme dynamo, although it was first patented by M. Zenobie Gramme, of Paris, as far back as 1870, is still much employed in modern electric installations. The Gramme was undoubtedly the first generator that produced absolutely continuous electric currents of great strength; and although various other modern machines are now capable of doing the same, the Gramme can still hold its own against any of these both as regards simplicity and efficiency.

The peculiarities of the Gramme dynamo centre chiefly in the construction and principle of its ring-shaped armature, the theory of which has already been fully explained in Chapter II. In practice the armature is not exactly of the same construction as the one there described, but nevertheless the principles embodied in the two are identical.

The core of the armature consists of a continuous coil of soft iron wire, which is constructed in a circular ring-shaped form. On the core are wound a number of coils of insulated copper wire, the ends of which are all joined so that the whole of the coils form one continuous and endless circuit. At the point where the extremity of the wire forming one coil is joined to that of its neighbour there is attached one end of a piece of metal, the other extremity of which is connected with a brass or copper strip rigidly fixed on the shaft on which the armature is placed. There are exactly as many of these strips as there are coils of wire on the armature, and each of them is insulated from the others and from the shaft. Attached to the framework of the machine so as to rub upon the surfaces of these strips as the shaft revolves, are two contact brushes made of hard copper. These brushes, which can only touch two of the metal strips at once, are placed at points diametrically opposite to one another, and lead off the electric current as it is generated in the armature coils.

Fig. 18 will explain the working of the armature. N and S are the poles of the field magnets, and A is the shaft to which the ring is attached. On this shaft will also be observed the ends of the copper strips connected with the junctions of

the wire forming the armature coils, which for the sake of simplicity are represented in the drawing as being of only a single convolution each. As the shaft and armature revolve, the brushes P and P′ rub upon the surfaces of the copper strips. If the working of this armature be compared with that illustrated in fig. 4, page 11, it will be at once observed that the principle involved in each is exactly the same, and that it is only in the arrangement of the contact brushes that there is any difference. Therefore, just as was the case in the arrangement previously illustrated, when the shaft and armature are made to rotate in the magnetic field between the two poles of the magnet, a current of electricity constant in direction and

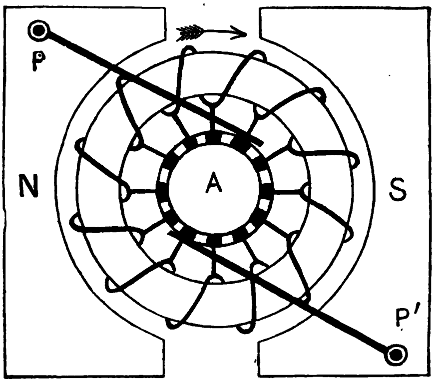

FIG. 18.—The Gramme Ring.

practically uniform in strength is set up through the external circuit from one of the contact brushes to the other.

The arrangement of brushes rubbing upon the surfaces of insulated metal strips fixed on a revolving shaft is found in all continuous current dynamo machines, and is called a commutator. The brushes are generally made movable, so that they can be adjusted to bear upon the metal strips at exactly the required points, and also so that they can be removed and renewed when worn out. Since the position of the points of contact between the commutator strips and brushes has considerable influence on the strength of the current generated, it

is possible in some machines to regulate the latter by altering the position of the brushes. A considerable amount of electric energy is sometimes lost at the commutator by what is known as sparking. As the shaft rotates, and the brushes make and break contact with one metal strip after another, minute electric arcs are formed at the points of contact, and the metal of both brushes and strips is burnt away. When the brushes are adjusted so as to touch the strips at exactly the proper points for efficient working, sparking is reduced to a minimum; however, it always takes place, more or less. The magnetic field of the Gramme dynamo is produced by four electro-magnets, two of these being placed above and two below the armature. Each pair has a common pole piece, which envelops nearly half of the circumference of the armature, which thus revolves in an extremely powerful magnetic field. In the smaller machines it is usual to connect the magnet coils in series with the armature, and the machine is thus made self-exciting. In the case of the larger generators a small separate generator of the same type is generally employed, the sole duty of which is to supply the current necessary to excite the field magnets. The two machines are often placed on one bed plate, so that their armatures can be fixed to the same shaft and rotated together by means of a single pulley.

The following table gives some statistics as regards the modern form of the continuous current Gramme dynamo:

Class	H.P. required (actual)	Revolutions per minute	Weight	No. of arc lamps	Candle-power of each (actual)	No. of incandescent lamps of 20 candle-power each
			cwts.			
A	$2\frac{1}{2}$	900	$3\frac{3}{4}$	1	3,000	25
A_1	4	1,400	$3\frac{3}{4}$	2	3,000	—
A_2	4	1,400	$3\frac{3}{4}$	4	1,000	—
E	12	1,000	10	5 or 6	2,500	60
H	12	1,100	10	10	1,000	80
H_1	10	1,100	10	10	1,000	—
M	$1\frac{1}{2}$	1,400	$1\frac{1}{2}$	1	1,000	12
B	6	700	7	1	5,000	50
C	8	800	$9\frac{1}{2}$	1	10,000	—
D	12	600	20	1	20,000	—

When these machines are used to supply current to incandescent lamps a separate exciter is invariably employed, the 'A' machine being specially designed for this purpose.

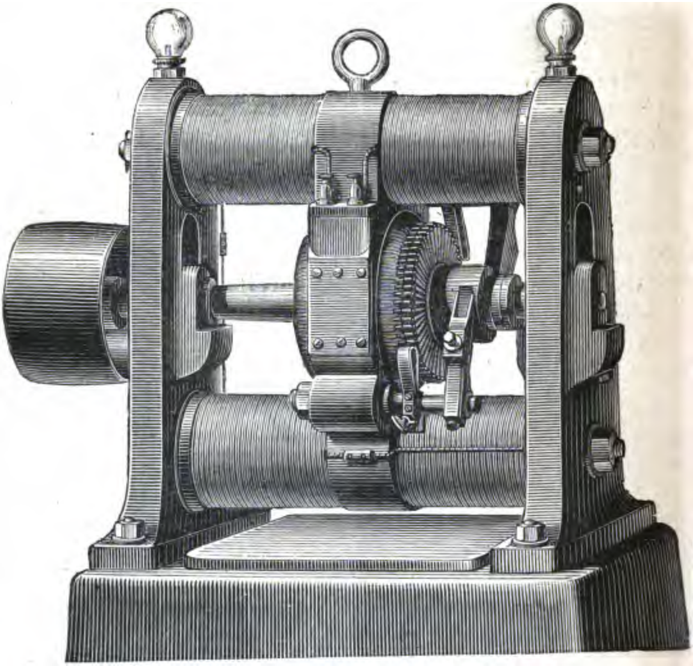

FIG. 19.—Gramme Continuous Current Machine.

The Alternating Current Gramme Machine.

Another and totally different form of dynamo has been designed by M. Gramme in order to supply alternating currents suitable for illumination by means of electric candles. In this machine the Gramme ring is retained, but its construction and the manner of its employment are somewhat altered. In the continuous current machine the ring is revolved between the poles of the field magnets. In the distributor, as the alter-

nating machine is commonly called, the ring is fixed and stationary, and the field magnets revolve within it. The core of the ring is, as before, made of soft iron ; it is, however, rather wider, and approaches in form a drum or hollow cylinder. On the core are wound coils of insulated copper wire. In the manner in which these coils, which are eight in number, are wound, we find something totally different to their arrangement in the armature of the continuous current machine. In the latter the coils are all wound in the same direction and joined together so as to form one continuous circuit. In the alternating armature, on the contrary, each successive coil is wound in the opposite direction to the one before ; that is to say, they are alternately right and left handed. Thus, of the eight coils, four are wound one way and four the other. The free ends of the wire are also not joined together, but are brought to the outside of the machine and attached to brass terminal screws.

The field magnets, also eight in number, are formed of flat iron cores attached radially, like the spokes of a wheel, to a shaft which revolves in bearings in the centre of the armature ring. These magnets are wound with insulated copper wire in alternate directions like the ring, and thus their exterior poles are alternately north and south. The current necessary to excite the magnets is obtained from a separate generator of the continuous current type, and the connection with the revolving magnet coils is made through two insulated brass cylinders on the shaft, rubbing on which are two brass or copper contact springs. The magnet coils and separate generator are connected in circuit so as to form one continuous circuit. When the shaft and field magnets are caused to rotate, the poles of the latter pass the coils of the armature in rapid succession, and induce in them electric currents. Since, however, the poles of the magnets are alternately of north and south polarity, owing to each successive magnet being wound differently to the one before it, the currents generated are changed in direction every time a fresh magnet passes. The currents produced by this machine are therefore what are called alternating, and the machine is an alternating dynamo. As a separate current is induced in each of the armature coils, several

separate circuits can be supplied with electricity at the same time by one machine, or all the coils can be connected together so as to produce a single current of great intensity. In some of the later forms of this generator each of the armature coils is wound with two wires. When a current of high electromotive force is required, these are joined up in series end to end: when, on the other hand, electric quantity is wished for, the internal resistance of the armature is reduced by joining the wires together so as to form parallel circuits, the two wires being then equivalent to a single wire of double conducting power.

Since he designed the above machine, M. Gramme has brought out another of improved form in which there are but six electro-magnets, and in which the exciting and distributing apparatus are combined, the need for a separate machine to excite the magnets being thus obviated.

Siemens Generators.

Among the most efficient of modern dynamo machines are those invented by Messrs. Siemens. This firm, which has manufactories in England and in Germany, has brought out both continuous current and alternating forms of generators, each of which can be made specially suited for supplying currents for either arc or incandescent lamps.

The Siemens continuous current machine differs chiefly from the one invented by Gramme in the form and construction of its armature. The field magnets are, however, also of different design, and with the single exception of a striking similarity between the commutators employed in each, the two machines are totally different in construction and appearance.

The Siemens armature, which was invented by Herr von Hefner Alteneck, one of the managers in the firm of Siemens and Halske, of Berlin, is of the drum-shaped or cylindrical class. It consists primarily of a hollow copper cylinder, which by means of an internal iron frame is mounted rigidly on a metal shaft which passes through its axis, and which can be

made to revolve by means of a pulley at one extremity. On the cylinder are wound a number of coils of insulated copper wire. These are laid on longitudinally, so as to be parallel to the axis, and cover the entire surface and ends of the cylinder. The extremities of the wire forming the coils are joined together in series, and are also connected with the metal strips of a commutator similar to that of the Gramme continuous current machine. The manner in which this connection is formed is shown in fig. 20, and is such that when the armature is rotated in a magnetic field, a continuous electric current can be led off from the contact brushes. The induction of the

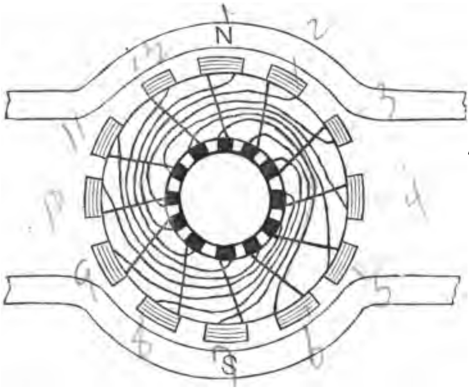

FIG. 20.—Siemens Armature.

current is owing to the fact that those parts of the coils which lie on the surface of the cylinder, cut the lines of magnetic force when the armature is made to revolve on its axis. The wire which passes over the cylinder ends is therefore inoperative, and is only useful as forming part of the circuit. In order to make this inoperative portion of the wire bear as small a proportion as possible to the rest, the armature is made considerably greater in length than in diameter.

Fig. 21 is a sectional end view of the whole machine, and shows the arrangement of the field magnets. The magnet cores are formed of curved soft-iron bars, usually fourteen in number. Seven of these are placed above and seven below

the armature, which revolves in the cylindrical space left between the curved portions. The straight parts of the magnets are fitted with four flat coils of insulated copper wire, which are connected together in series, and wound so as to produce in the iron a north pole above and a south pole below the armature. The free space between the armature coils and the inside of the magnets is made as small as is consistent with the necessity of their never coming in contact, which would destroy the insulation of the armature and render the machine

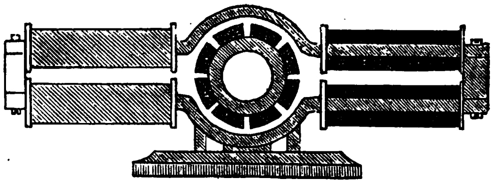

FIG. 21.—Siemens Horizontal Continuous Current Machine.

useless. Since the power of the magnets to induce currents in the coils varies inversely as the square of the distance between them, the smallness of the space between the two in the Siemens generator adds very considerably to its efficiency.

In the self-exciting machines the magnet coils are placed in a shunt circuit or are joined in series with the armature according to the nature of the lamps with which they are to be used. Where several machines are working together, however, it is often found convenient to employ one of them to supply the magnets of the others with current.

Since the machine illustrated in fig. 21 was designed, Messrs. Siemens have brought out another continuous current generator of rather different appearance. Here the magnets are fixed vertically above and beneath the armature, and the magnetic poles are produced at the sides. A machine of this class is illustrated in fig. 22.

The tables on p. 56 give the different sizes of the machines supplied by Messrs. Siemens in this country, also the power required to drive them, and the effect produced.

The Siemens alternating machine produces currents the

direction of which is changed every instant. This generator, which is shown in fig. 23, consists of a circular metal disc, attached to the edge of which are a number of oval bobbins wound with insulated wire. The disc is fixed upon a horizontal shaft, and revolves between two frames carrying electro-magnets

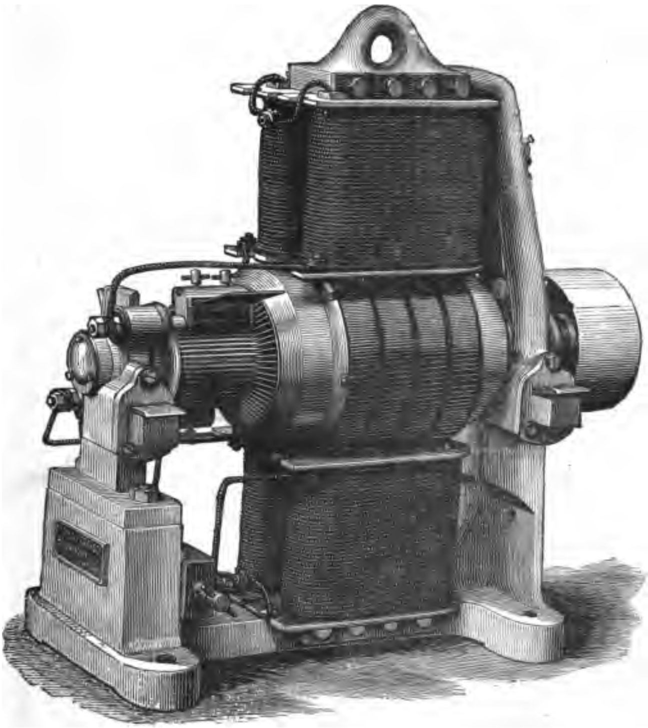

FIG. 22.—Siemens Vertical Continuous Current Machine.

arranged in circles. These magnets, which are equal in number to the bobbins on the disc, are arranged with their opposite poles facing one another, and as the disc revolves the bobbins are caused to pass between them. Electric currents alternating in direction are thus induced in the bobbin wire.

Series Machines for use with Arc Lamps.

Type of machine	Number of lights	Light-power in standard candles of each light	Diameter of pulley in inches	Width of machine strap in inches	Number of revolutions per minute	Horse-power required, about
D_{00}	1	50,000	15	9	400	20
D_0	1	30,000	12	8½	500	15
D^1	1	12,000	11¾	4	550	7
D^2	1	6,000	8½	3½	600	4
D^7	1	3,000	6½	3	950	3
D^8	1	2,000	7	3	950	2½
D^6	1	1,200	4¾	2½	1,300	2
D^5	1	500	4½	2½	1,200	1½
$S\,D_7$	3	1,000	6½	3	950	3
$S\,D_8$	6	1,000	8½	3½	950	5½

Shunt Wound Machines for Lighting Incandescent Lamps.

Type of machine	Number of lamps	Diameter of pulley in inches	Width of machine strap in inches	Number of revolutions per minute	Horse-power absorbed, about
$S\,D_5$	12	5	2½	1,500	1¾
$S\,D_7$	25	6½	3	1,000	3½
$S\,D_2$	50	8½	4	900	6

These machines are also made in larger sizes for lighting a larger number of lamps.

The electro-magnets, which are connected together in series, are excited by a separate continuous current machine, and the armature bobbins can either be made to supply a number of separate circuits, or by being connected together to produce a single current of great strength. These machines are employed with both arc and incandescent lamps.

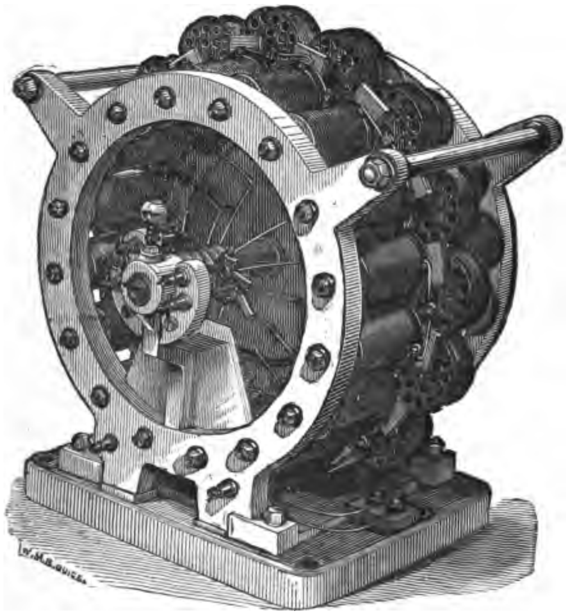

FIG. 23.—Siemens Alternating Current Machine.

In the following tables it will be noticed that each generator consists in reality of two separate machines—W being the distributor and D the exciter.

Alternate Current Machines for Arc Lamps.

Type of machine	Number of arc lights	Diameter of pulley in inches	Width of machine strap in inches	Revolutions per minute of the alternate current machine, about	Revolutions per minute of the exciter, about	Horse-power absorbed by the two machines
$\frac{W_3}{D_5}$	4 to 8	8 / 4½	4¼ / 2	700 to 800	1,100 to 1,200	4½ to 6
$\frac{W_6}{D_6}$	8 to 12	8 / 4¾	4½ / 2½	650 to 700	1,000 to 1,100	5 to 9
$\frac{W_2}{D_6}$	12 to 18	10 / 4¾	6½ / 2½	560 to 650	1,200 to 1,300	8 to 11
$\frac{W_1}{D_6}$	16 to 24	12 / 4¾	9½ / 2½	500 to 700	1,400 to 1,500	12 to 18
$\frac{W_1}{D_7}$	24 to 32	12 / 6½	9½ / 2½	500 to 650	1,200 to 1,300	18 to 22

Alternate Current Machines for Incandescent Lamps.

Type of machine	Number of lamps	Diameter of pulley in inches	Width of machine strap in inches	Approximate number of revolutions per minute	Approximate horse-power actually required
$\frac{W_3}{D_5}$	60	8 / 4½	4¼ / 2	750 / 1,100	6
$\frac{W_6}{D_6}$	80	8 / 4¾	4½ / 2½	650 / 1,000	8
$\frac{W_4}{D_6}$	120	10 / 4¾	6½ / 2½	650 / 1,200	12
$\frac{W_1}{D_7}$	200	12 / 5½	9½ / 2½	650 / 1,200	20

The Edison Generator.

The Edison dynamo consists of an armature of peculiar construction, which revolves between the poles of very long and powerful electro-magnets. The current produced is continuous, and is led off by copper contact brushes which bear on a commutator attached to the armature shaft.

The Edison armature is formed of a central metal core built up of a very large number of exceedingly thin soft-iron discs, which are bolted together upon a horizontal shaft with sheets of tissue paper, talc, or other insulating substance placed between them. Around the solid cylinder so formed are arranged longitudinally a number of straight copper bars, which are insulated from one another and attached at their extremities to an equal number of copper discs in such a manner that the whole arrangement of bars and discs forms a circuit similar to that found in the insulated wire of the Siemens continuous current armature. Half of the number of copper discs are placed at one end of the armature and the other half at the other end; and each disc is insulated from the others by other discs composed of talc, ebonite, or prepared paper. The use of copper discs is simply to form a connection between the copper bars, and the whole arrangement is in principle exactly that of a continuous insulated wire wound longitudinally over a solid cylindrical core so as to cover the whole of the latter, including the ends. Since both bars and discs are of considerable section, the resistance of the whole armature is exceedingly small. The commutator is formed of insulated copper strips arranged round the armature shaft. There are exactly as many of these strips as there are bars or copper discs in the armature, and each strip is connected with one of the latter. There are two sets of contact brushes rubbing on the strips, each set consisting of two or more separate copper springs in order to reduce sparking.

In the smaller machines the magnetic field is produced by a vertical electro-magnet consisting of two long soft-iron bars of cylindrical cross-section, wound with insulated wire from end to end. The two legs of the magnet are connected together at the top by a rectangular piece of iron, while at the bottom

are the two pole pieces, which are exceedingly massive and bored out so as to embrace the armature. The magnet coils

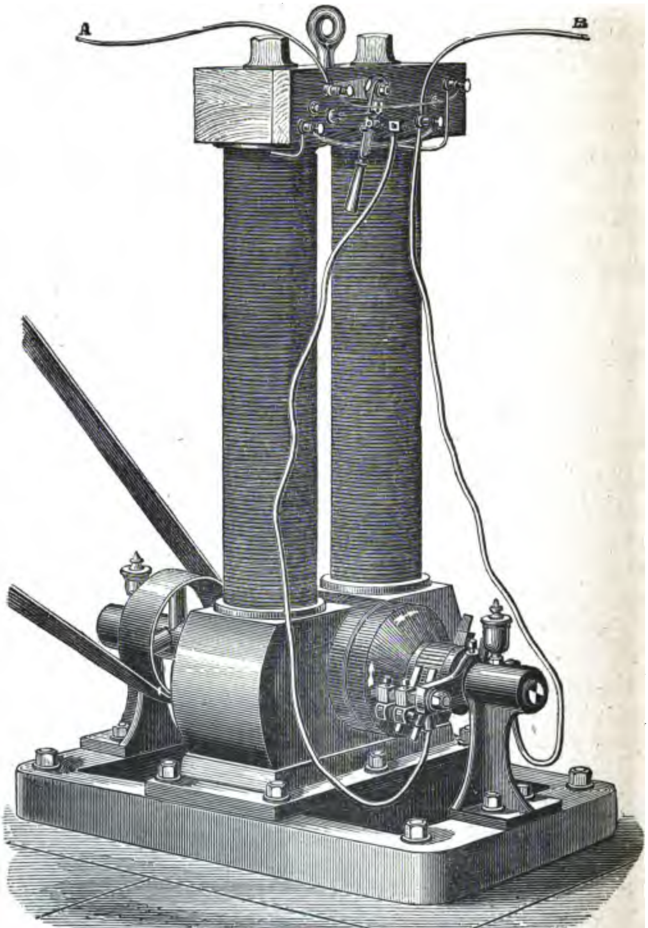

FIG. 24.—Edison Z Dynamo for 60 Lamps.

are placed in a shunt circuit, and by means of an arrangement by which more or less resistance can be switched into this circuit, the magnetic field is made of more or less intensity,

and the currents induced in the armature regulated. A general view of one of the smaller sizes of the Edison generator is given in fig. 24.

The efficiency of the Edison machine is very high, and it is said that as much as 90 per cent. of the power exerted in driving it is converted into electricity. In the larger generators there is also another advantage met with. Since the speed required is comparatively low, the armature can be worked direct on the same shaft as a steam engine fixed alongside, and the nuisance of belts and pulleys thereby avoided.

To Mr. Edison belongs the credit of having manufactured some of the largest dynamos yet built. In the enormous machines recently put up in the Holborn Viaduct, in London, the armature has 108 copper rods, is five feet in length, 28 inches in diameter, and weighs over five tons. The magnetic field is produced by electro-magnets consisting of twelve iron cores each eight feet long and wound with thick insulated wire. These are placed horizontally and attached to pole pieces of unusual weight. The armature is fixed on a horizontal shaft, and is worked direct by a 150 horse-power steam engine at the rate of 350 revolutions per minute. The total weight of the dynamo and steam engine taken together is about twenty tons, and the current developed is sufficient to supply 1,200 Edison incandescent lamps each of sixteen candle-power.

The following table gives particulars of the various sizes of Edison dynamo, the lamps mentioned being each equal to sixteen standard candles :

Edison Dynamo Machines.

Dynamo	Capacity	Power required	Revolutions per minute	Pulley		Floor space	Extreme height	Weight	Electromotive force	Maximum safe current armature will carry
				Diam.	Face					
	lamps	h.-p. indicated		"	"	′ ″ ′ ″	′ ″	lbs.	volts	ampères
E	15	2½	2,200	5	3	2 1 × 1 5½	2 11	700	110	13
Z	60	8	1,200	10	6	3 8½ × 3 3	6 0	3,000	do.	52
L	150	19	900	14	9	5 3 × 3 3	6 6	6,000	do.	132
K	250.	32	900	14	9	5 10½ × 3 3	6 6	8,250	do.	220
C	1,200	150	350	engine	attached	13 6 × 8 8	6 4	60,330	do.	1,000

An improved form of dynamo has recently been produced by Dr. Hopkinson. It is a modification of the original Edison machine, and is called the Edison-Hopkinson dynamo.

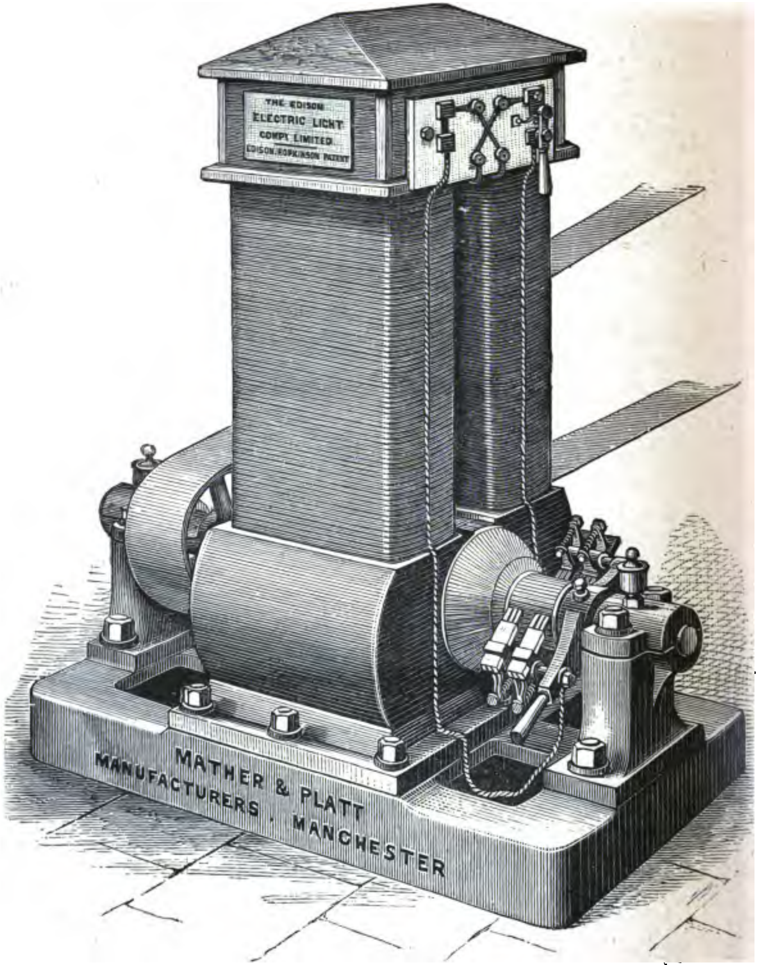

FIG. 25.—Edison-Hopkinson 250-Light Slow-Speed Dynamo.

The Edison-Hopkinson dynamo is illustrated in fig. 25

The following are its chief advantages over the older Edison machine: 1. Increased efficiency in converting mechanical energy into electricity. 2. Cost and weight of the machine per lamp reduced. 3. The new machine can be run at a lower speed than formerly, rendering possible direct driving off the engine.

These advantages have been obtained by increasing the cross-section of the field magnet cores, decreasing their length, and adding to the length of wire in their coils.

The use of multiple field magnets, as used in the larger forms of Edison dynamo, is discontinued, their place being taken by round, oval, or oblong solid field magnets, one for each pole piece. By making these alterations, the magnetic field has been greatly intensified, and the machine rendered more compact. At the same time the speed necessary to maintain the electromotive force has been reduced, and when not restricted to a low speed more power may be employed, the speed increased, a larger number of lamps supplied, and the cost of the machine per lamp very considerably lessened.

The subjoined tables give the principle data of the old and new machines, and from them the superiority of the latter may be readily observed.

Edison Dynamo.

Dynamo old form	Safe lamp load	Speed to obtain 110 volts	Height over all	Floor space	Weight	Floor space occupied per lamp	Weight per lamp
			' "	' " ' "	lbs.	sq. foot	lbs.
Z	60	1,200	6 0	3 8 × 3 3	3,000	·2	·50
L	150	900	6 6	5 3 × 3 3	6,000	·11	40
K	250	900	6 6	5 10 × 3 3	8,250	·076	33

Edison-Hopkinson Dynamos.

Safe lamp load	Speed to obtain 110 volts	Height over all	Floor space	Weight	Floor space per lamp	Weight per lamp
light		' "	' " ' "	lbs.	sq. foot	lbs.
125	550	4 10	3 2 × 2 5	3,024	·061	24
250	500	4 11	5 3 × 2 5	5,152	·052	20
500	600	7 5	5 9 × 3 3	11,536	·037	23

The Brush Machine.

The Brush dynamo is a continuous current generator, chiefly suited for supplying electricity for arc lamps.

The armature is of the Gramme type, but the manner in which the coils are connected to the commutator, the commutator itself, and the arrangement of the field magnets, are entirely original.

The core of the armature is formed of a cast-iron ring of rectangular cross-section, and is fixed on a horizontal revolving shaft. The coils, which are usually eight in number, are quite separate from one another, and are composed of insulated copper wire wound in deep grooves formed at regular intervals in the iron of the ring. The inner end of each coil is connected with the inner end of the coil which is diametrically opposite to it on the ring; and the other end is joined to a commutator of peculiar construction, formed as follows: On the armature shaft, and insulated from it and from one another, are a number of copper cylinders, there being one of these for every pair of coils on the armature. Each of these cylinders is split longitudinally, as shown in sectional view (fig. 26), in

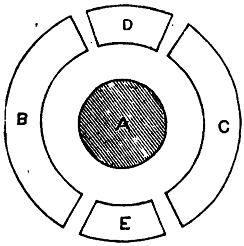

FIG. 26.

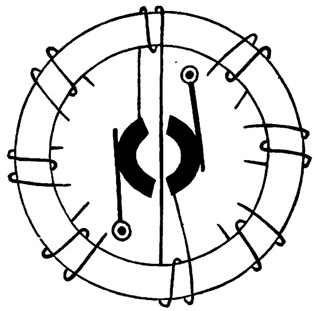

FIG. 27.

which A is the shaft, and B, C, D, and E, the four sections into which each of the cylinders is divided.

In connection with each of these split cylinders are two contact brushes, which touch at diametrically opposite points

and tap the currents induced in the armature. Every pair of armature coils is connected with its particular cylinder (as shown in fig. 27), which is a diagrammatic end view of the armature and commutator, and shows one pair of coils connected. It will be noticed that, as the shaft and commutator cylinder revolve, there will occur two intervals, during which the brushes will be in contact with D and E, and the coils thus switched entirely out of the circuit. The machine is so arranged that this takes place when the position of the coils is such that little or no current is being induced in them. As there are four pairs of coils, each of which is differently located on the armature ring, it is arranged that there shall always be three pairs in circuit while one pair remains idle. In this manner the coils are only in circuit when they are doing work, and are switched out when not producing a current, so as to prevent their adding to the total resistance of the armature, or offering a separate channel for the electricity to flow through. Since a separate current is induced in each pair of coils, every pair of brushes can be made to supply a distinct circuit. Since, however, the circuit is interrupted by the commutator twice in every revolution of the armature, the current generated, though constantly in the same direction, would not be continuous, but intermittent. It is therefore usual to connect the brushes together in parallel circuit or in series as either strength or high electromotive force is wanted, and only produce one current from a machine. The field magnets are arranged at the sides of the armature, as shown

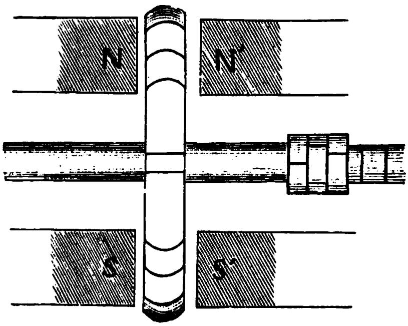

FIG. 28.

in fig. 28, where N N′, S and S′, are the magnetic poles. It will be noticed that there are two poles on each side of the armature, those of the same polarity being opposite to one another.

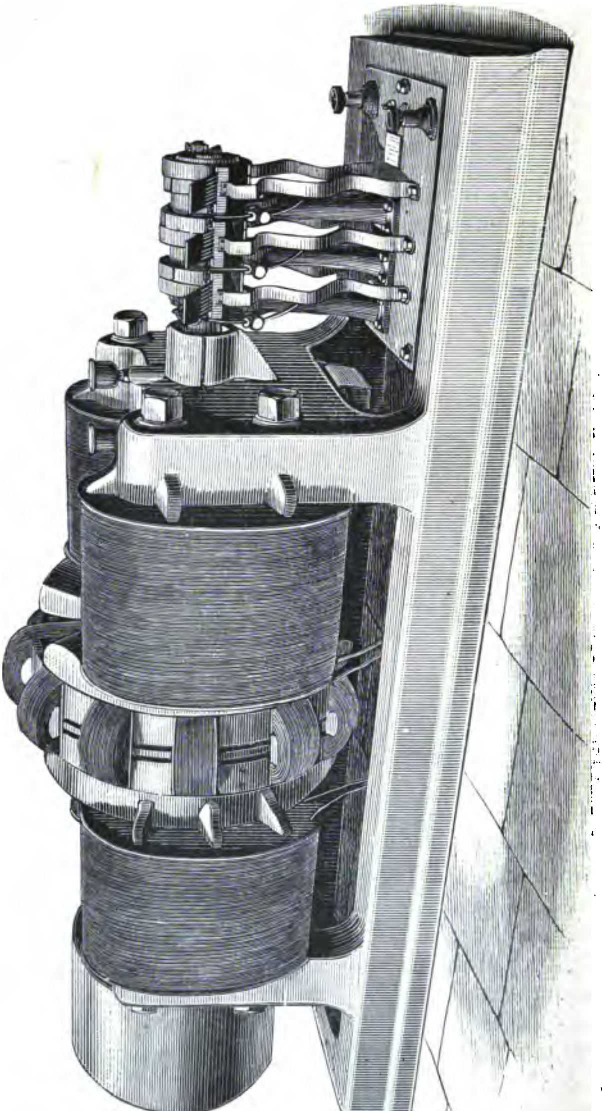

FIG. 29.—The Brush Machine.

Each of the pole pieces is of sufficient size to cover three armature coils, leaving one pair uncovered, this pair being the one switched out of the circuit at the time by the commutator. The magnet coils are connected in a shunt circuit, or placed in series with the armature according to the electrical arrangements of the working external circuit.

The Brush machine is shown in perspective in fig. 29.

Brush Dynamo Machines for use with Arc Lamps.

Number of machine	Number of lamps	Candle-power of each	Horse-power required	Weight in lbs.	Revolutions per minute	Size of pulley in inches	Width of belt in inches
2	1	1,500	1½	260	1,000	5	3
3	2	1,500	2½	400	1,100	6	3
4	3	2,000	3½	550	1,100	6	4
5	6	2,000	6	1,150	900	10	4½
6	10	2,000	10	1,500	850	14	6
7	16	2,000	14	2,500	800	14	8
8	1	80,000	30	4,800	650	20	12
8	40	2,000	36	4,800	700	20	12

The Brush generator for incandescent lighting has but lately made its appearance. This machine is an altered form of a dynamo due to Mr. Schuckert of Nüremberg, which in turn is little more than an improved Gramme. The new machine is called the 'Victoria' dynamo, and is illustrated in fig. 30. The armature is a Gramme ring, the core of which is formed of a large number of thin soft-iron discs, and wound with coils of insulated wire in the usual manner. This armature revolves upon a horizontal shaft between the pole pieces in connection with eight electro-magnets excited by a shunt current. The pole pieces are formed so as to embrace the sides of the armature as well as its circumference; and since there are four of them, and consequently four neutral zones in the magnetic field, the commutator is fitted with four contact brushes. Owing to this arrangement one machine can be made to supply two separate circuits at once. It is, however, usual to couple the brushes together so as to produce a single current of great strength. In another form of this machine there are three armatures all revolving upon the same shaft between separate pole pieces.

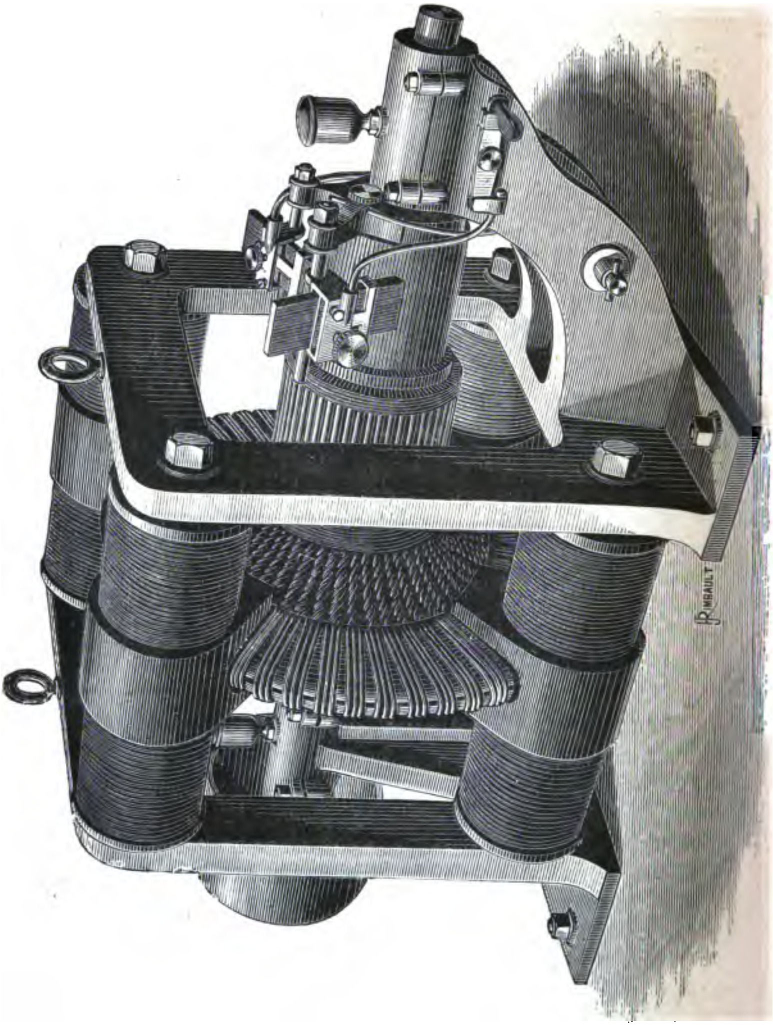

FIG. 32.—Brush 'Victoria' Dynamo for Incandescent Lamps.

The Gülcher Dynamo.

The Gülcher dynamo, named after its inventor, is the property of the Gülcher Electric Light and Power Company, and is used chiefly in connection with Gülcher arc lamps and Crookes incandescent lamps.

It consists of eight electro-magnets arranged in sets of four upon two vertical circular plates, through the centre of which passes the armature shaft.

The inward extremities of each opposite pair of magnets are connected together by a U-shaped pole piece, the four pole pieces, which do not touch one another, forming a kind of hollow cylindrical box or cell in which the armature revolves. In this manner the pole pieces embrace the armature so as to bring the whole of the wire thereon within the limits of the magnetic field, the lines of force in which are cut at right angles.

The armature is of the Gramme ring type, but the coils are arranged so as to leave spaces between them, the object of these spaces being to catch the air and keep the armature cool.

The armature coils are connected to a commutator of the ordinary Gramme pattern, and sparking is almost entirely avoided, and wear much lessened by the employment of contact brushes of unusual width.

The Gülcher machine is arranged to give currents of very low electromotive force—65 volts—the lamps supplied being connected in parallel circuits.

The Bürgin Generator.

The Bürgin generator as manufactured in this country by Messrs. Crompton & Co. has an armature consisting of a number of Gramme rings and field magnets similar to those employed in the horizontal form of Siemens' continuous current machine as shown in fig. 22. The cores of these magnets, however, instead of being of wrought iron and divided into separate bars, consist of two iron castings which are bolted together at their external extremities and accurately bored out in the centre to receive the armature.

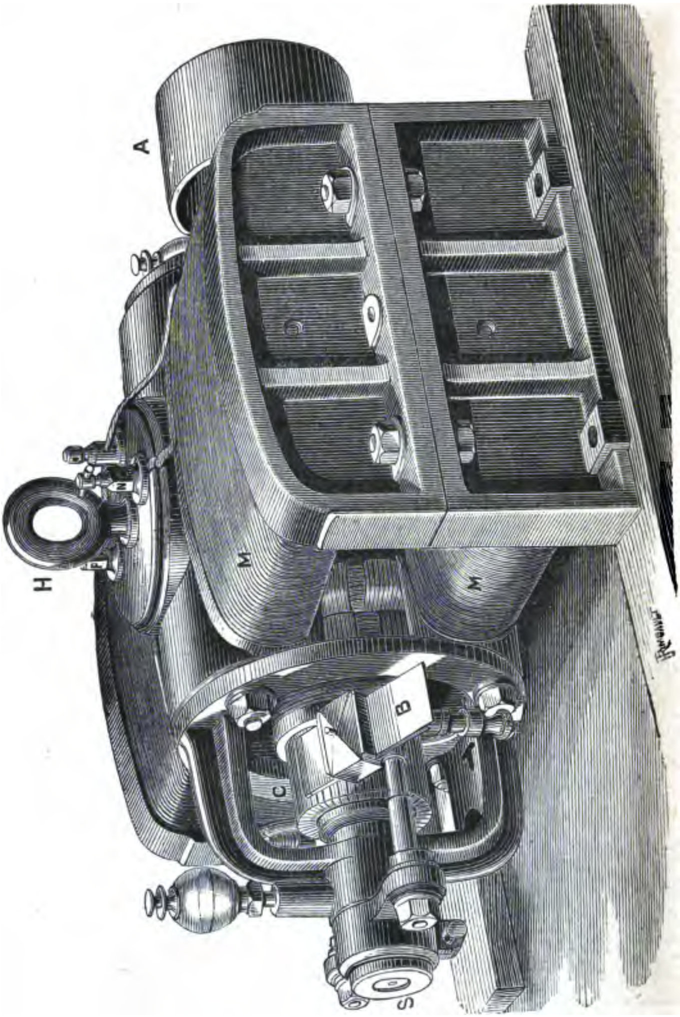

FIG. 31.—The Bürgin Machine,

Fig. 31 shows the general appearance of the Bürgin machine, and fig. 32 a half section.

M M are the magnets of which I I are the pole pieces.

S is the armature shaft carrying the driving pulley. A and R are the armature coils.

The Bürgin armature is illustrated in fig. 33. It consists of

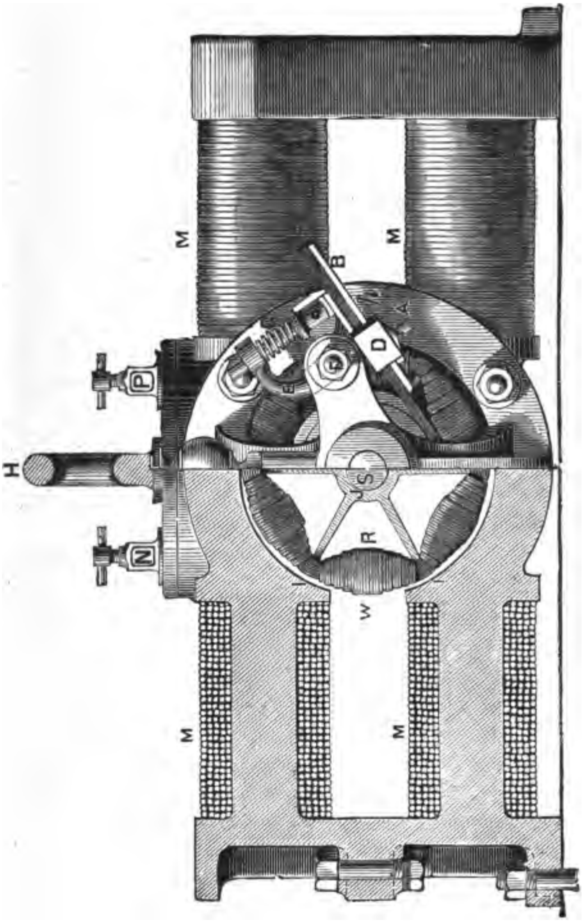

FIG. 32.—Half-section of the Bürgin Machine.

eight hexagonal rings or frames of square cross-section, formed of soft-iron wire, the sides of each frame being wound with separate coils of insulated wire after the Gramme fashion.

These hexagonal rings are all mounted side by side on one shaft, S, in the manner illustrated, being fixed to the shaft by means of radial spokes which are attached to the ring cores at the bare places between the coils. Each ring is placed $\frac{1}{24}$ of its circumference in advance of the one before it, and the whole of the coils, forty-eight in all, are connected together so that the coils successively in advance of the others are from ring to ring in one single and continuous circuit. The points of junction between the coils are further connected to commutator strips of phosphor-bronze, C, on which bear contact brushes, B, formed of hard sheet copper.

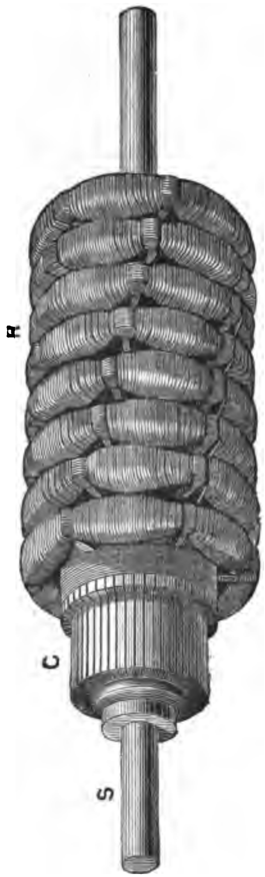

FIG. 33.
The Bürgin Armature.

Owing to the manner in which the several armature coils are placed, the one slightly in advance of the others, one of the coils at least is always moving in that part of the magnetic field when the inductive effects of the magnets on the wire are greatest. The current produced by the whole armature is therefore extremely uniform and continuous.

The field magnet coils, of which there are four, are connected together in series, and either placed in the same circuit as the armature, or supplied with current from a separate generator.

The chief advantages of the Bürgin machine may be summed up as follows.

The construction of the machine is extremely simple. The magnet cores form at the same time the whole frame and bed-

plate, the bearings of the armature shaft and the commutator brushes being attached to iron plates bolted on at each end of the armature chamber.

The open nature of the armature—the fact of the rings not being covered with wire over their entire surface—renders it possible to drive the machine at a high speed without any danger of the armature heating, which is a great source of trouble in many dynamos.

Again, owing to the construction and material of the magnet cores, the central armature chamber can be accurately bored out so as to allow of the armature running with the coils in very close proximity to the magnetised iron, thus obtaining a maximum inductive effect.

The machine also runs very steadily with a total absence of vibration, and the current generated is continuous with very little undulation.

The Bürgin dynamo is employed for supplying current to both arc and incandescent lamps. For arc lights the magnets are usually excited by being placed in circuit with the armature, or by a separate and smaller dynamo. For working incandescent lamps, however, a different and somewhat novel system is employed under the name of Crompton and Kapp's patent compound winding. In this arrangement the field magnets are wound partly with main wire in series with the armature and the external circuit; and partly with shunt wire of high resistance coupled up parallel with the armature. Machines on this principle maintain a constant electromotive force in the external circuit, no matter what number of lamps within the limit for which the machine is constructed are burning at any given time.

The Bürgin machine is constructed in sizes to supply any number of incandescent lamps from 50 to 500, the speed of the smaller machine being 1,800 revolutions per minute, that of the larger 1,000, with intermediate sizes in proportion.

The Elphinstone and Vincent Machine.

The Elphinstone and Vincent dynamo is a generator of very recent date and high efficiency designed by Lord Elphin-

stone and Mr. Charles W. Vincent. Fig. 34 is a sectional end view of this machine. The armature consists of a hollow cylinder made of *papier mâché*, on the outer surface of which are attached longitudinally eighteen flat coils wound with double wire, so as to form thirty-six distinct sections. The chief peculiarity of this armature is that it contains no iron, and hence the currents induced in the coils are entirely due to the wire moving in a magnetic field, without any assistance from the alternate magnetisation and demagnetisation of an iron core.

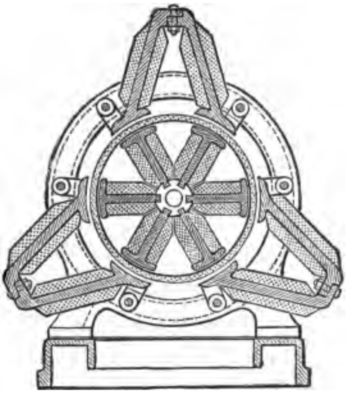

FIG. 34.—Section of the Elphinstone and Vincent Machine.

The field magnets are twelve in number, six being situated outside and six within the armature, which is caused to revolve between them. Since the armature with its coils are extremely thin, the poles of the inside and outside magnets that are opposite to another can be placed very near together, and the magnetic field produced between them is thus of very great intensity.

The armature coils are joined together in series, and also connected with the strips of a commutator, exactly as in the Gramme machine. In connection with the commutator there are six contact brushes, from which continuous currents are led off. The field magnet coils are so arranged that they can be readily connected together either in series or in parallel circuits. For incandescent lighting they are placed in a shunt circuit, and when working with arc lamps in direct circuit with the latter and the armature. The lightness of the armature and the absence of all iron in its construction render it possible to run the machine at a very high rate of speed without any danger of heating. At present the highest speed attained is 1,000 revolutions per minute, but alterations are now being made with

a view to produce a machine capable of running at 1,500 revolutions.

The principal peculiarities of the Elphinstone and Vincent generator are, firstly, the V-shaped form of the external field magnets; secondly, the employment of internal magnets with their poles facing the external ones; thirdly, the absence of all iron in the armature, and the peculiar construction of the latter and its coils. The following are the different sizes of these machines at present manufactured:

Elphinstone and Vincent Dynamo Machines.

Types of machine	No. of 20 candle-power Swan lamps it can drive	Horse-power required
A	80	8
B	120	12
C	200	20
D	300	30
E	400	40

At the normal speed of 900 revolutions per minute, the electromotive force of the current generated by the E machine is about 80 volts.

The Gordon Generator.

The Gordon dynamo is a machine recently designed by Mr. J. E. H. Gordon, and constructed at the Greenwich works of the Telegraph Construction and Maintenance Company.

In this machine, as in the Gramme distributor, the armature coils are stationary, and it is the field magnets that revolve. There is also no commutator, and the currents generated are alternating. The Gordon is at present the largest dynamo ever constructed, surpassing even the large Edison generator in the number of incandescent lamps that it can maintain.

There are 128 oval armature coils with V-shaped soft-iron cores fixed at regular intervals round two vertical ring-shaped frames. In the space between these there revolves on a horizontal shaft another circular frame 8 feet 9 inches in diameter, carrying sixty-four cylindrical field magnets, thirty-two on each side.

The magnets are excited by a current of from forty to fifty ampères generated by one or more separate continuous current dynamos.

The armature coils are so arranged that they can be connected together in parallel circuits of from one to four in series. When all the coils are in separate parallel circuits, and the magnets revolved at 200 revolutions per minute, a current of 5,600 ampères with an electromotive force of 60 volts is generated, this being sufficient to maintain 5,000 20-candle-power Swan incandescent lamps. Again, if the coils are arranged in parallel circuits of four in series, and the number of revolutions of the magnets be 140 per minute, the current produced is of an electromotive force of 88 volts, and sufficient to light 1,300 lamps of the same candle-power.

The total weight of the machine described is eighteen tons, of which seven go to the magnets and the framework that revolves with them. The machine is driven by a steam engine coupled direct on to the magnet shaft. In a still larger generator of more recent design, 1,600 horse-power is absorbed in driving the magnets at 150 revolutions per minute. The electro motive force is 70 volts, and the current of sufficient strength to maintain 15,000 incandescent lamps.

The Lumley Machine.

The Lumley is a new machine of very simple construction. The field magnets, four in number, are of cast iron, and of similar form to those in the horizontal continuous current Siemens and Bürgin machines.

The armature core is formed of thin sheet-iron discs punched out into the wheel-like shape shown in fig. 35. A number of these discs are fixed side by side on a shaft, with brass rings placed between them. The coil thus formed is wound between the spokes with longitudinal coils of insulated copper wire, in the same manner as a Gramme ring. In the illustration, A is the shaft, B a gun-metal boss fixed on the latter into grooves, on the surface of which the inner spoke-like projections of the discs are fitted. D is one of these discs, and C the

coils, only two of which are shown. The armature revolves on the shaft in a hollow chamber formed by the pole pieces of the magnets, and the currents generated are led off from a pair of brushes rubbing on commutator strips connected to the coils. These currents are continuous, and suitable for arc or incandescent lamps, as the magnet coils are placed in series with the armature or in a shunt circuit.

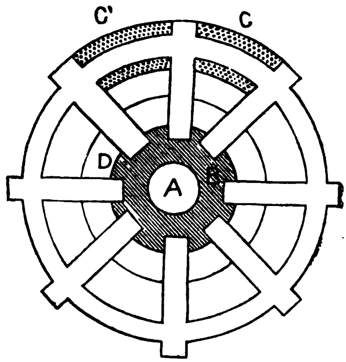

FIG. 35.—The Lumley Armature (section).

The chief advantages of the machine are its simplicity and the construction of the armature, which is easily made and not liable to become heated. The efficiency claimed is also extremely high. The following are the different types of this machine in use:

Lumley Machines.

For Incandescent Lighting			For Arc Lighting		
No.	No. of Swan lamps, each of 20 candle-power	Horse-power required	No.	No. of lamps	Horse-power required
B	50	5	1 A	4	4
B	70	6·75	2 A	5	5
B	100	9	3 A	9	9
B	200	18	4 A	18	18
B	500	45			
B	1,000	90			

The Ferranti-Thompson Machine.

The Ferranti-Thompson machine, patented by Sebastian Ziani de Ferranti and Alfred Thompson, and brought out with the co-operation of Sir William Thompson, is a generator of the alternating current type. In the arrangement of the frame and field magnets there is considerable similarity to the alter-

nating Siemens dynamo, but the Ferranti has an armature of entirely original and novel design.

We have seen that in most dynamos the conducting part of the armature is formed of copper wire of a thickness correspondingly more or less great as strength of current or high electromotive force is required, the only exception so far being the Edison machine, where the armature is composed of copper bars and discs. Now, in the Ferranti dynamo neither wire nor bar is employed, and we find a third class of conductor in the shape of a copper ribbon.

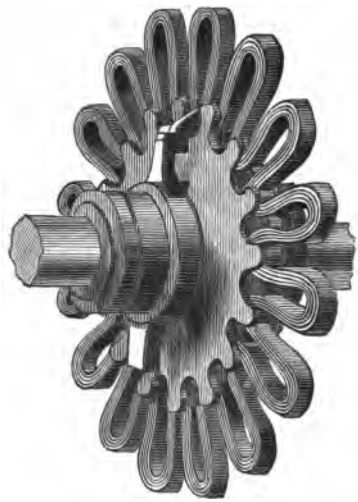
FIG. 36.—Ferranti Armature.

The construction of the Ferranti armature is shown in fig. 36. It consists of a steel shaft carrying a ring or boss to which is attached by means of pins a zigzag coil formed of a continuous length of copper ribbon, 120 feet long, half an inch wide, and one-twelfth of an inch in thickness, wound in a single coil of twelve layers with insulating tape between its convolutions, so that a current to pass through it must flow round the whole of the layers.

There is no commutator, and the two ends of the ribbon are connected to two insulated metal collars, which revolve with the armature and on which rub two metal blocks pressed forward by springs, these blocks serving to lead the current to the external circuit.

On each side of the armature is fixed a set of electromagnets, each set being in number equal to the number of undulations in the armature. The poles of the magnets, which are in cross-section of similar shape to the interior of the ribbon undulations, are placed facing one another on opposite sides of

the armature, those on the same side being alternately of opposite polarity, and the north poles on one side opposite to the south poles on the other. The magnet coils are connected together in series, and excited by means of a continuous current obtained from a separate generator.

Since the armature ribbon is only half an inch in breadth, it is possible to place the poles of the opposite magnets very near together. The usual distance is three-quarters of an inch, and then the armature revolves in a magnetic field of remarkable intensity. In the smaller machines the armature is driven at the very high speed of 1,900 revolutions per minute, at which pace the direction of the current generated is charged no less than 30,000 times every minute, or 500 times in a second.

In a large 1,000-light Ferranti machine of recent construction, the armature, which is 30 inches in diameter, contains three copper ribbons, separated from one another by means of strips of vulcanised fibre ; and as each ribbon makes ten turns round the armature, there are in all thirty layers. The armature contains eight undulations, and is run at 1,400 revolutions per minute between two sets of sixteen electro-magnets.

Up till recently a Siemens machine was usually employed to supply current for the field magnets of Ferranti machines, but a continuous current Ferranti for this purpose has now been designed.

Owing to the simplicity of the construction of the Ferranti dynamo and the small weight of copper required, it is capable of being built very cheaply. This advantage, coupled with its high efficiency and small weight and bulk, should obtain for it a place among the best generators of the present day. There is, however, one disadvantage which must not be overlooked. The high speed at which the armature is driven, which in itself is one of the causes that lead to the efficiency of the machine, is apt to cause deterioration of the working parts. High-speed machines cannot, moreover, be connected direct on to a steam engine, but must invariably be driven by a system of belting which is always more or less objectionable, leading as it does to unsteadiness of motion, vibration, and noise. In order to obviate this, a new form has lately been designed, which, when

run at 300 revolutions per minute, is calculated to supply current sufficient for 500 incandescent lamps. In this slow-speed machine the required circumferential velocity is obtained by increasing the diameter of the armature to 36 inches. The armature helix has, moreover, sixteen undulations, being formed of a copper strip 1 inch wide, 2 millimetres in thickness, and 470 feet in length, separated by paper covered with asbestos paint into eighteen layers or convolutions.

The Hopkinson and Muirhead Machine.

Another generator of somewhat similar design to the Ferranti, and, like it, having copper ribbon in place of wire in the armature, has been patented by Dr. J. Hopkinson and Dr. Alexander Muirhead.

There are two forms of this machine—the one producing continuous, and the other alternating currents. In both of these the field magnets are arranged in much the same manner as in the Ferranti and alternating Siemens machines. Instead, however, of the magnets being covered with wire, they are wound with insulated copper ribbon.

Between the poles of the field magnets revolves the armature, which is constructed in the following manner. On a circular boss, fixed upon a horizontal shaft, there is wound a considerable amount of sheet-iron ribbon, each convolution of which is insulated from the others by asbestos paper. On the sides of this composite wheel-like structure, slots or grooves of a zigzag pattern are cut, in which are fixed, one on each side of the armature, two zigzag continuous coils of copper ribbon similar to that employed in the Ferranti machine. In the alternating form of machine the undulations in the ribbon on each side of the armature are opposite to one another, but in the continuous current form, instead of this, the undulations on one side are slightly in advance of those on the other. By this means when one undulation is at the point of its minimum efficiency, the corresponding one on the other side of the armature is at its maximum, and thus the current generated is very continuous and uniform.

In another armature of the same description, the copper ribbon, instead of following a zigzag course, is bent so as to form twenty-four coils or bobbins of oval shape. In other respects the arrangement is the same, and, as before in the continuous current machines, the bobbins on the opposite sides of the armature are one slightly in advance of the other.

In the continuous current machines there is a commutator of peculiar form with several contact brushes. The arrangement is such that before the contact between one of the brushes and one of the commutator strips is broken, a resistance is first introduced which, gradually increasing, diminishes the current, and thus prevents sparking. The principal points of difference between the Ferranti and the Hopkinson and Muirhead machines are as follows :

In the Ferranti armature there is no iron, and but a single coil of copper ribbon.

The field magnets are usually wound with wire.

Alternating currents, only, are generated.

In the Hopkinson and Muirhead machines, on the other hand, the armature has a core consisting of bands of sheet iron, and there are two coils of copper ribbon, one on each side of the core.

The field magnets are wound with copper ribbon instead of with wire.

One class of machine produces alternating currents, and the other is fitted with a commutator and gives currents continuously in one direction.

The Maxim Machine.

The Maxim machine, invented by Mr. H. S. Maxim of New York, has field magnets of almost exactly the same construction as have already been described on page 54 with reference to the Siemens machine. The armature is on the Gramme principle, being, however, elongated and taking more the form of a cylinder than that of a ring.

In some of these generators there are two commutators, one at each end of the armature shaft. When this is the case the armature coils are connected alternately with one and the

other, and two distinct currents can be obtained. The field magnets are connected together in series, and are usually excited by a separate generator.

As in the Gramme and Siemens machines, the current generator is continuously in the same direction.

The Maxim machine is largely used in America in connection with the incandescent lamps of the same maker; it will, however, be rarely met with in this country.

The Weston Machine.

Another American invention is the Weston machine, which comprises a Siemens armature of peculiar construction with magnets that resemble those in the continuous current Gramme.

The armature core is formed of thin iron plates stamped out into wheel-like shapes very similar to those in the Lumley machine, as shown in fig. 35. The coils, however, instead of being wound, as in the Gramme ring, are passed right over the whole core, as in the Siemens armature. The commutator is also of slightly different form, as the segmental strips on which the brushes rub are not straight but helical. This arrangement is stated to equalise the currents. The field magnets are twelve in number, six being placed above and six below the armature, which revolves between two pole pieces, as in the Gramme machine. The magnet coils are in series with the armature, and the current generated is suitable for burning arc lamps. The open framework which forms the armature core is very favourable to the dissipation of heat, and a speed of 900 to 1,000 revolutions per minute can therefore be attained without any danger of the temperature rising too high.

The principal dynamos that are employed in this country for electric lighting have now been described. No doubt many other machines exist, some of which are of excellent design and high efficiency. Most of them are, however, but modifications of the better known machines, and few of them have been employed to any very great extent.

It seems improbable that dynamo machines will be ever invented having a much higher efficiency than those at present

in use. Nearly 90 per cent. of the mechanical energy absorbed by a high-class modern dynamo is converted into electric energy; more than this cannot well be expected.

It is rather in the direction of increased size and greater simplicity that dynamos are likely to be improved. In large towns, at any rate, it is more than probable that before long central stations will be established, from which electric currents sufficient to maintain thousands of lamps will flow through radiating conductors. For such stations, generators of great size and power, capable of supplying current to a large number of lamps, will be required. Hence increase in the dimensions of the machines is one of the chief roads to improvement still left open. Another is simplification and consequent reduction in cost. The simpler the working parts of a generator are, the less likely is it to get out of order, the less is the expense of repairing it when out of order, and the smaller is its first cost.

From the above it follows that the dynamos of the future, though they may not be very much more efficient than those of the present day, will probably be of much larger size and of simpler construction.

CHAPTER VI.

ARC LAMPS.

The Construction of Arc Lamps—Carbons—Arc Lamps of Gaiffe, Serrin, Wallace-Farmer, Siemens, Rapieff, Crompton, Brush, Weston, Pilsen, Hedges, Gülcher, Brockie, Lever, Akester, Abdank—Future Progress in Lamps—Electric Candles of Jablochkoff, Rapieff, Wilde, Jamin.

If two rods or pencils of compressed carbon be placed with their ends in contact and connected with conducting wires so as to form part of the external circuit of a dynamo-electric generator, it is found that, provided the carbons be sufficiently thick, the current passes through them without any sensible effect. If, however, one of the pencils be slightly withdrawn so as to leave a space of about one-eighth of an inch between it and the extremity of the pencil, a curious phenomenon immediately takes place. The extremities of both carbons become intensely heated, and emit light of dazzling brilliancy, while between them is formed an electric discharge or arc. This arc is believed by some experimentalists to consist of minute particles of incandescent carbon which are carried by the current from the positive to the negative point, while others consider that the flow of matter is in the opposite direction and that the carbon is in a state of vapour. The greater part of the light comes from the extremities of the carbons, and not from the arc itself. The positive carbon, that is to say the pencil through which the positive current first flows, gradually assumes at its extremity a concave form, while the end of the negative pencil remains constantly pointed. Both pencils also slowly burn away, the positive one being consumed at twice the rate of the other. Owing to this, the space between the two points gradually

becomes greater, and the arc consequently lengthens, till at last, when the interval becomes too great, it suddenly goes out in consequence of the current ceasing to pass. An arc lamp, or, as it is sometimes called, an arc regulator, is an appliance for holding the carbon pencils in their proper position, and for feeding them towards one another as they burn away, so as automatically to maintain the points at a uniform distance apart, and the arc of a constant length. In lamps where the pencils are placed vertically one above the other, it is usual to place the positive one at the top, for the concave form that it takes acts as a reflector and throws down the light of the arc. This may be seen from fig. 7, page 15. The carbon pencils employed in arc lamps are usually of cylindrical form, and are made in lengths to suit the lamp. They vary in diameter from a quarter to three inches. When the pencil is too thin, it burns away too rapidly; while when it is too thick for the current that is passing, it does not burn away regularly, and is apt to form several small arcs instead of one large one.

We have seen that Sir Humphry Davy in his experiments with the electric arc employed charcoal electrodes. Charcoal, however, wastes away extremely rapidly, is liable to split, and cannot be easily made in long pieces. In all modern arc lamps the pencils are made of carbon. The carbon is that found encrusted in the interior of gas retorts. It is ground up, mixed with gum, sugar, or some other adhesive preparation, moulded into sticks, and baked. Some makers mix with the carbon magnesia, potash, soda, and other substances which are found to influence the strength and steadiness of the light and the durability of the pencils. In some manufactories the pencils, after being moulded, are subjected to great pressure in a hydraulic press.

In order to reduce the resistance of the pencils, which when they are long is very considerable, it is usual to electroplate them with copper. Besides reducing their resistance, this has the further advantage of making it much easier to obtain a good electric contact in the lamps between the pencils and the conductors conveying the current.

We will now proceed to describe some of the best known of modern arc lamps.

The Gaiffe Lamp.

In the Gaiffe lamp the carbon pencils are placed vertically one above the other, the positive one being uppermost.

As shown in the illustration, the negative carbon is fixed at its lower end in a holder which is attached to an iron rack with teeth cut in one side of it. These teeth engage in a small toothed wheel fixed on an axle which is impelled to turn so as raise the rack by means of a coiled spring. On the same axle there is another toothed wheel of larger diameter, in connection with which is a second rack carrying the upper or positive carbon. As this rack is on the opposite side of the axle, the spring, while it tends constantly to raise the negative carbon, will at the same time lower the positive one, and thus force the two points into contact. Encircling the lower extremity of the rack attached to the negative carbon is a hollow solenoid, or coil of insulated copper wire, which forms part of the circuit between the negative carbon and the dynamo. When the carbon points are in contact and the current passes, the solenoid acts exactly like an electro-magnet, and sucks the iron rack into itself, separates the carbon points, and forms the arc. Again, when the arc becomes too long through the carbon being consumed, the current is weakened, the coiled spring is able to overcome the attractive power of the solenoid, and the two carbons approach one another. Thus the length of the arc is automatically regulated by the current.

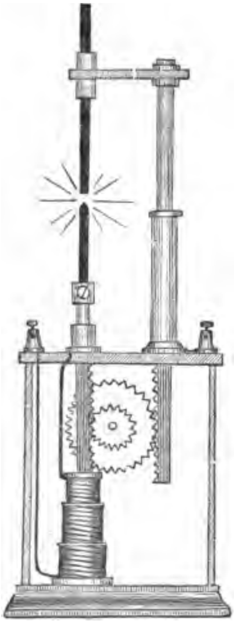

FIG. 37.—Gaiffe's Lamp.

If by any chance the lamp should go out altogether, the

action of the solenoid would at once cease, and the spring would force the carbons into contact, again the solenoid would separate them to the proper distance, and the arc would be re-established.

As the large wheel has twice as many teeth in it as the smaller one, the top carbon will descend twice as fast as the lower one rises. The top carbon is, however, the positive electrode, and therefore is consumed twice as fast as the other, consequently the position of the arc remains always the same.

The chief objections to this lamp are the coiled spring, which requires winding up, and the fact that the carbons employed must necessarily be short, and therefore require frequent renewal.

The Serrin Lamp.

In the Serrin lamp the position of the carbons is regulated by the combined action of an electro-magnet in circuit with the lamp, and a train of toothed wheels.

The carbon holders are arranged vertically, as in the Gaiffe lamp, and the positive carbon is uppermost.

At the lower extremity of the positive holder there is a rack gearing with a train of multiplying wheels, which, from the weight of the carbon and holder, tend always to revolve in one direction. An electro-magnet, the coils forming part of the circuit between the lower carbon and the dynamo, is fixed in the lower part of the lamp. In front of the poles of this magnet is an iron armature, which, when attracted, lowers the negative carbon, and, at the same time, causes a brake block to press on one of the train of wheels so as to prevent its rotation, thus stopping the descent of the positive carbon.

The mechanism acts in the following manner :

When no current is passing, and the magnet is consequently inoperative, the armature is kept away from the poles of the magnet by means of a spring ; the wheels are therefore free to revolve, and the positive and negative carbons remain in contact. The moment the current is turned on, the magnet attracts the armature, which, by means of the brake, locks the

train of wheels and fixes the positive carbon; while, at the same time, the negative carbon is slightly lowered, and the arc formed. When the current becomes weakened, through the arc being lengthened by the burning away of the carbons, the magnet, being no longer able to overcome the force of the spring, releases the armature and acts on the brake block so as to allow the wheels to make a few revolutions, and the upper carbon to descend through a short distance. Should the latter descend too far, the arc is again brought to its proper length by the lower carbon being attracted downwards by a further motion of the armature.

Thus the length of the arc is maintained constantly the same.

Since in this lamp it is only the positive carbon that is fed, it is obvious that the position of the arc will gradually descend as the negative carbon burns away. In order to remedy this, in an improved form of regulator the negative carbon is made to rise at a rate equal to half that at which the positive carbon descends.

The Serrin lamp is undoubtedly very ingenious, and if carefully attended to is found to work well. On the other hand, the complicated nature of its working parts renders it liable to get out of order where skilled attendance is unobtainable, and for the same reason its first cost is necessarily considerable.

The Wallace-Farmer Lamp.

The Wallace-Farmer lamp is used to a considerable extent in the United States; and if it has not been much heard of in this country, it is probable that this is more owing to the fact that the patent is held by the same company that own the Brush regulator, than because of any defect in the principle of the lamp itself.

In the Wallace-Farmer lamp the carbon pencils employed in other regulators are discarded, and plates of carbon are employed instead. These plates are placed one above the other in a metal frame, with their edges in contact. Attached to the upper plate, which is movable, is a rod in connection with the

armature of an electro-magnet, which, when the current passes, lifts the carbon. When this takes place, the arc is formed at that point between the plates where the space is least, and the resistance consequently smallest, and as the carbon is consumed it moves along horizontally until it reaches the extremity of the plates. When this is arrived at the current is slightly weakened, and the magnet allows the upper carbon to descend through a short distance. The arc then begins to travel along in the opposite direction, and when the other end is reached the operation is repeated.

The advantages claimed for this lamp are economy, simplicity, and steadiness. The lamp is certainly inexpensive to construct, and the carbon plates cost little and last a long time. The working parts are also extremely simple; and since the regulation of the position of the upper carbon takes place at intervals of over half an hour, the light produced is remarkably uniform. It is, however, difficult to obtain carbon plates that will burn regularly; and since the arc is partly inclosed, a large amount of the light produced is entirely lost.

The Siemens Pendulum Lamp.

The Siemens pendulum lamp, invented by Herr Von Alteneck, and constructed by Messrs. Siemens, is largely employed both in this country and in Germany.

In this lamp the lower carbon holder is fixed to a frame which hangs vertically beneath the regulating mechanism, and it is the upper carbon that moves. Attached to the upper carbon holder is a rack which, from its weight, tends constantly to descend and to turn a small pinion. On the same axle with the pinion is an escapement wheel, which cannot revolve without causing a pendulum to vibrate. When the lamp is burning, and the arc of normal length, the frame carrying the pinion and pendulum is lifted by the core or armature of a solenoid in circuit with the lamp, and in this position the pendulum is unable to vibrate, owing to a small lever which catches its extremity. Since the carbon holder cannot descend without turning the pinion, and the pinion is unable to turn without causing the

pendulum to vibrate, when the latter is caught by the lever, the carbon remains fixed and cannot descend.

As, however, the carbons burn away, the arc becomes longer and the current weakened ; the solenoid, no longer able to bear the weight, drops the frame, and the pendulum becoming disengaged from the lever vibrates, and allows the pinion to turn, and the upper carbon to descend. Again, as soon as the arc has returned to its normal length the current becomes stronger, and the solenoid raises the pendulum ; the latter is again caught by the lever, and the carbon is prevented from descending any further. In this manner, whenever the arc becomes too long, the solenoid through the pendulum escapement, pinion, and rack, allows the upper carbon to descend, and thus again reduces the space between the carbon points to the normal amount.

As the upper carbon alone moves, the position of the arc is variable, that is to say, it moves downwards at the same rate at which the lower carbon is consumed. In some lamps, however, such as those in which parabolic reflectors are employed, it is necessary that the position of the arc should be constantly the same.

In this case what is known as the Siemens abutment pole is employed. This consists of a small metal screw or knife edge, which presses on the lower carbon at the point where it begins to become conical. Attached to the other end of the carbon is a thin wire or cord, which, passing over a pulley and having a weight hanging from its free end, tends constantly to raise the carbon. It can, however, only do this as the carbon burns away, and allows the pencil, by means of the conical form of its extremity, to pass the abutment pole. In this way the arc extremity of the lower carbon is always maintained at a fixed point, and the upper carbon only descends sufficiently to compensate for its own consumption, instead of moving, as was the case before, at a rate equal to the consumption of both carbons together.

The mechanism of the lamp is usually contained in a metal case, and the carbons in a glass globe, which prevents from falling any fragments of hot carbon which may become de-

tached. In order to diffuse the intense rays of the light produced the globe is often frosted. A Siemens lamp and globe are shown in fig. 38.

FIG. 38.—Siemens Arc Lamp.

The Siemens pendulum lamp is a very practical invention. It burns well, requires little attention, is simple in construction, and can be looked after by inexperienced workmen. It has, however. a defect which is inherent to all lamps which are regulated directly by a solenoid or electro-magnet placed in direct circuit with the lamp and the dynamo. The defect is this. If several lamps be placed on one circuit, the weakening of the current produced by the arc in any one of the lamps is found in practice to act upon the regulating apparatus of all of them, and then the carbons are brought nearer together and the length of the arc reduced where not wanted. In order to overcome this defect, Messrs. Siemens have devised another form of lamp, which we will now proceed to describe.

The Siemens Differential Lamp.

In the Siemens differential lamp the pendulum feeding arrangement is much the same as in the lamp already described. Instead, however, of its action being controlled by one solenoid, there are two for this purpose, one of them being, as before, in series with the lamp, and the other in a shunt circuit.

Fig. 39 will explain this arrangement. P and P′ are the leading wires from the dynamo. A is a solenoid wound with many convolutions of fine wire, offering a considerable resistance. B is another solenoid wound with wire of large diameter and low resistance. A is placed in a shunt circuit, and B in series with the lamp. From the illustration it will be evident that the current which passes through the lamp and which arrives at P will have two paths open to it. It can either flow through the main solenoid, B, along the lever, F D, and back again to the dynamo through the carbons and their holders, C and C′, and the return wire, P′, or it can pass straight to P′ through the shunt solenoid, A. According to the law already stated in the earlier part of the book, the proportion of the total current that will flow through each of these paths will be inversely as the resistance of each.

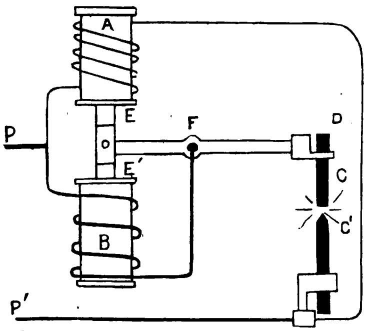

FIG. 39.—Siemens Differential Lamp.

Working within the two solenoids A and B are two soft-iron cores, E and E′, which are both attached to one end of a lever pivoted at F, and connected at its other end with the upper carbon holder, C. As to the action of the mechanism; when the proportion of the current passing through A is sufficient to make that solenoid exert a greater attractive power upon the core E than B exerts on E′, both cores will be raised, and consequently the other end of the lever D will be depressed. On the other hand, when the current that passes through the two solenoids is so divided between them that B attracts E′ more strongly than does A E, D will be elevated. In connection with D is the pendulum-feeding apparatus, so when E is raised and D depressed the pendulum is free to vibrate, and consequently the upper carbon to descend.

As already stated, the amount of current that passes through A to B respectively is inversely proportional to the

resistance of each of the two circuits in which they are placed taken from P to P′. Now, the only point in either of these circuits, the resistance of which can vary, is the point in the circuit of B where the arc is formed between the two carbons. This being so, if the length of the arc be normal, and the resistance of the two solenoids properly proportional, an amount of electricity will pass through each of them sufficient to exert an equal attractive force on both E and E′. These cores will therefore remain in a state of equilibrium, and the pendulum of the feeding apparatus will be prevented from vibrating, and consequently the upper carbon from descending. When, however, a certain amount of the carbon has been consumed, and the arc thereby lengthened, the resistance of the B circuit will become greater than it was before. Less current will, therefore, flow through B, and to compensate for this more through A. The effect of this will be that the equilibrium of E E′ will be destroyed, the cores being raised and D depressed. Owing to this the pendulum of the feeding arrangement will commence to vibrate, and the upper carbon will descend. As soon, however, as the arc has regained its normal length, the comparative resistances of the two circuits will again return to what they were before; the cores will once more be lowered and D raised, the pendulum stopped from vibrating, and the carbon from descending further.

In this manner the length of the arc is regulated entirely by the variations in the proportion of current that passes through each of the solenoids, owing to the variations in the resistance in the circuit of one of them caused by the arc itself, and without any regard whatever to the total amount of current that passes through the lamp. It is therefore possible to place many of these lamps in series on a single circuit without their in any way interfering with one another.

As in the pendulum lamp, when a constant focus is required, Siemens' abutment pole, as described above, is applied to the lower carbon, which then rises at the same rate at which it is consumed.

With the differential lamp either continuous or alternating currents are employed. In the first case the positive carbon

burns away nearly twice as fast as the negative carbon, while the former takes a concave and the latter a pointed shape. When alternating currents are used, the two carbons are consumed at exactly the same rate, and both burn to a point.

The carbon pencils employed in the Siemens lamps vary from ·35 to 1·20 inch in diameter, and are made in lengths to burn from four and a half to sixteen hours without renewal.

The Rapieff Lamp.

In the Rapieff lamp we find an arrangement entirely different to any of those previously described. Instead of the customary pair of carbon pencils, we find that there are four, and moreover that the feeding of these as they burn away is performed without mechanism of any description.

The carbon pencils are arranged in pairs, two above and two below the arc, each pair representing one electrode or point. The upper electrode consists of two carbons inclined together at an angle of 90°, so as to meet in the form of the letter V at the uppermost part of the arc. The two pencils are free to slide between rollers which direct their motion and form the electrical contact.

Fine silk cords in connection with a weight cause the carbons to move downwards, but when their points come into actual contact they are unable to advance farther except at the same rate at which they are consumed. Thus the upper electrode of the arc is maintained constantly in the same position. The lower electrode consists of a similar arrangement of two more carbons, the angle in this case, however, being inverted, and the carbons pointing upwards. When the lamp is not burning, the two electrodes are kept in contact by a spring; but directly the current is turned on, an electro-magnet, concealed in the base of the stand, draws back the lower pair of carbons a certain distance and starts the arc, which, as the four carbons can only advance as they are consumed, remains of constant length. Should the current be interrupted the electrodes are brought again into contact by the spring, and will remain in this position, being only separated by the action of the current itself.

The carbon pencils in this lamp can be renewed, one at a time, without extinguishing the arc; and should the lamp go wrong, a resistance equal to that of the arc is automatically shunted into the circuit by the electro-magnet, and thus the extinction of one lamp does not affect others burning on the same circuit. In another form of lamp Mr. Rapieff places both pairs of carbons side by side so as to form a species of pyramid with the arc at the apex. Above this a piece of lime or kaolin is held so that the arc plays upon the latter, beats it to incandescence, and produces a very soft and agreeable light.

The chief point of difference between the Rapieff and other regulators is that instead of clockwork or electro-magnetic arrangements as generally employed, the feeding of the carbons, and consequently the position and length of the arc, is regulated by means of the principle of the intersection of two straight lines, the position of the electrodes being kept constantly the same by the carbons composing each impinging against one another. The feeding is therefore continuous, and the steadiness of the arc benefits accordingly.

The carbon pencils employed are of small diameter, and when burning with continuous currents, the upper pair are made twice as long as the others. This is because they receive the positive current, and consequently burn away the fastest. With alternating currents carbons of equal length are employed.

The Rapieff lamp has been successfully employed to light the printing office of the 'Times' newspaper. For some reason, however, it has not been much heard of lately.

The Crompton Lamp.

In the Crompton lamp a shunt solenoid regulates the feeding of the positive carbon, while a solenoid in the main circuit moves the negative carbon so as to establish the arc in the first instance.

In fig. 40, P P′ are the leading wires from the dynamo, C is the positive, and C′ the negative carbon holder. A is a double solenoid in series with the main circuit. When the lamp is not

in action, the lower carbon holder C′ and the cores D of the main solenoid are supported by a spiral spring, and the carbon points remain in contact. The moment, however, the current passes, the solenoid A attracts the cores D sufficiently to overcome the resistance of the spring, lowers C′, and separates the carbons, thus establishing the arc. The solenoid B, which is in a shunt circuit across the terminals of the lamp, is for the purpose of regulating the rate of advance of the positive carbon, which descends as the carbon points are consumed. Attached to the positive carbon holder C is the rack R, which in descending causes a train of wheels to revolve. On one of these, W presses a spring S, which is also connected to the movable core of the shunt solenoid B. When the arc is of normal length, the current that passes through B is very small, and insufficient to affect S, which therefore presses on W with force enough to prevent its revolving. The upper carbon is consequently fixed and cannot descend. As soon, however, as the arc becomes long and the resistance of the main circuit high, more current flows through the shunt, B raises S and allows W to revolve until the rack and the positive carbon have descended far enough to restore the arc to its proper length, when the wheels are once more stopped by the spring, and the motion of the carbon arrested. This arrangement is in practice so extremely delicate that although a complete revolution of the wheel W only advances the position of the positive carbon through a distance of one two-hundred-and-fiftieth part of an inch, W often makes but a quarter of a revolution at a time, thus shortening the arc by only the one-thousandth of an inch.

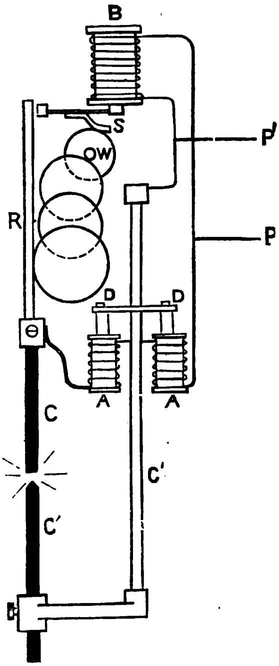

FIG. 40.—Crompton Arc Lamp.

Since the feed mechanism is entirely actuated by the varying amount of current that is caused to pass through the shunt solenoid by the varying resistance of the arc, and without any relation to the total amount of current that passes through the entire circuit, several of these lamps can be burned in series on one circuit. The Crompton lamp is essentially a practical contrivance, and the whole of the working parts are arranged and put together with a view to durability and efficiency. It is usually employed in connection with the Bürgin dynamo, of the same maker.

The Brush Lamp.

The Brush lamp, invented by the same American gentleman as the Brush dynamo, is one of the most practical of arc regulators, and has, perhaps, been more extensively employed for lighting large areas than any other electric lamp.

The Brush is what is known as a *clutch* regulator. A solenoid, partly in series and partly in a shunt circuit, acts upon a clutch arrangement, which shortens and lengthens the arc according to the current, and at the same time feeds the positive carbon as required.

Fig. 41 represents a Brush lamp with the cover removed from the chamber containing the working parts. A is a hollow solenoid wound with two separate wires, one of these being a short thick wire of small resistance, forming part of the lamp circuit, and through which the greater part of the current passes. The other wire, which is wound in a direction opposite to the thick wire, is of high resistance and many convolutions, and forms a shunt circuit across the lamp terminals.

When a current is passing through the lamp, if the arc is of normal length, the greater part of the current flows through the main wire and very little through the shunt. In consequence of the inductive effect of the current in the main wire, the core B is sucked into the solenoid with considerable force. When the arc becomes long through the burning away of the carbons, and the resistance of the arc circuit consequently high, less current flows through the main wire of the solenoid and more through the shunt. The effect of the latter is to neutralise the

inductive action of the former, and hence the solenoid no longer tends to attract the coil B with the same force. Since the number of convolutions of the shunt wire is greater than that of the other, and since also the shunt wire is wound next to the core, it takes but a slight amount of current flowing through the shunt wire to neutralise the attractive effects of a larger amount flowing through the main wire. Passing through the core B, which is hollow, is a brass rod D forming the positive carbon holder. Encircling this rod is the loose washer or ring, F, through which, when left to itself, D can slide without difficulty. Attached to the core B is the lifting finger C, the lower extremity of which catches the outer rim of the washer at a point opposite to the set screw H. When B is attracted into the solenoid, and C lifted, F is raised at one edge, and thus jams tight on the holder D, which, if the upward movement is continued, is lifted with it. S S are spiral springs, which support the core B. G is the negative carbon holder.

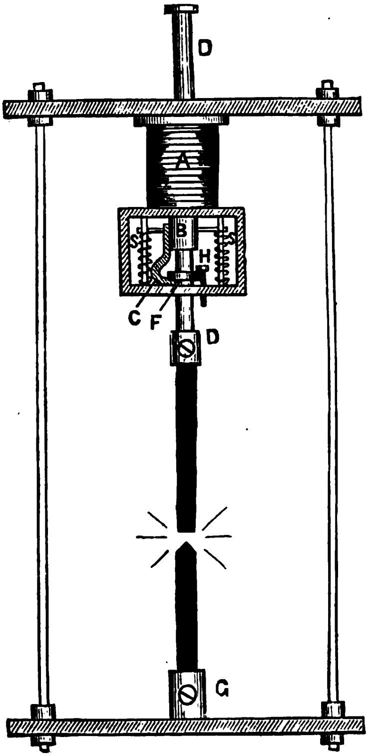

FIG. 41.—The Brush Lamp.

The action of the lamp is as follows :

When no current is passing, the holder, D, is free to descend, and the positive carbon rests upon the negative carbon. When the current passes, it flows through the two solenoid coils inversely as the resistance of the two circuits of which they

form parts. When the carbon points are in contact, the resistance of the main circuit is very low, and the current flowing through it proportionally powerful; the latter is therefore sufficient to neutralise the opposite tendency of the shunt current. The core, B, is therefore sucked into the solenoid. By means of C the core first tilts the washer, F, sufficiently to grip the holder, D, and then raises the washer, holder, and positive carbon until further motion is arrested by the washer coming in contact with the projecting head of the adjustable set screw, H. Thus the arc is established of a fixed length regulated beforehand by the set screw. As the carbons are consumed the arc gradually becomes longer, and at the same time the resistance of the main circuit greater. Consequently, the current that flows through the main solenoid wire becomes gradually less, while that which passes through the shunt increases. At length a time comes when the influence of the main current is neutralised by that of the shunt, hence A can no longer support B, which consequently drops, loosens the washer, and allows the holder of the positive carbon to descend until the arc regains its normal length, when the solenoid becomes once more able to raise B, tilt F, and arrest any further motion.

In this way the action of the current on the clutch mechanism is such that when the current is made to pass, the arc is immediately established of a fixed length, and as the carbons burn the positive carbon descends at the proper rate. To prevent the positive carbon falling too rapidly when released by the washer, the holder is made hollow and contains a mixture of glycerine and water. The holder can only descend as this solution passes a fixed piston, the motion is therefore slow and regular.

Fig. 42 shows a cut-out arrangement by which a lamp, if extinguished, is instantly switched out of the circuit and prevented from interfering with other lamps burning on the same circuit, which but for the current would also go out.

E is a solenoid wound with two wires like the regulating solenoid in the lamp. Both coils, however, are wound in the same direction. Connected to the movable core of the solenoid is the lever L, pivoted at M. K is a piece of brass con-

nected to one end of the main wire of the cut-out solenoid. When L is raised, it comes in contact with K. The other connections are all shown in the figure. P and P′ are the lamp terminals, and the other letters are the same as in the preceding illustration.

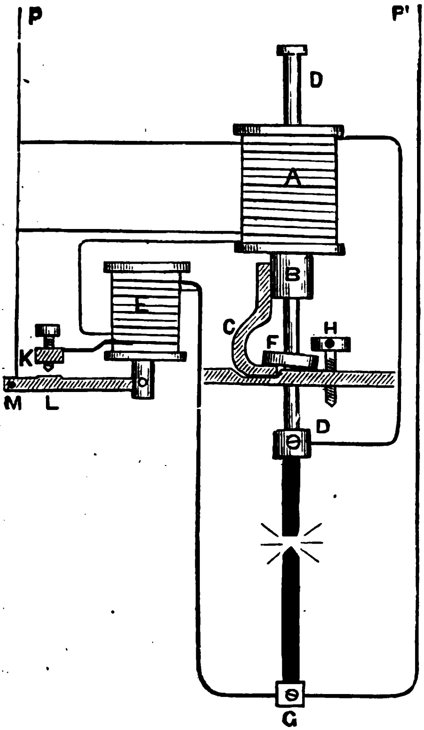

FIG. 42.—Connections in the Brush Lamp.

When the arc is extinguished, the whole of the current flows through the shunt wire, E, lifts the core, and with it the lever, L, which closes the cut-out circuit at K, and thus forces a new path through which the current can flow entirely separate from the lamp circuit.

The greater part of the current now passes through this cut-out circuit ; but since part of it is formed of wire wound round E, L is still attracted, and the contact at K is maintained. Thus when through the breaking of a defective carbon or other accident one lamp in a circuit is extinguished, that lamp is at once switched out of the circuit, the current passes as before, and other lamps are not affected. The carbon pencils employed in the Brush lamps are electro-plated with copper in order to reduce their resistance. When the lamp is required to burn for a long period two pairs of carbons are used, both regulated by the same solenoid. There are, how-

ever, two separate clutch washers, and one of these is adjusted so as to maintain one holder slightly above the level of the other. Hence the arc is only formed between one pair of carbons at a time, the second pair not coming into use until the first are entirely consumed.

The delicacy of the clutch arrangement and the differential system on which the regulating solenoid is worked, together with the action of the automatic cut-out, allows a large number of lamps to be burnt in series on the same circuit. As many as forty have been employed in practice.

With the ordinary lamp a single pair of carbons burn for eight hours, two pairs for sixteen. Each lamp requires an electromotive force between its terminals of about forty-five volts.

Since it is the upper carbon only that moves, the arc gradually descends, and a constant focus is not maintained; this, however, is of no importance for general illuminating purposes for which the lamp is designed.

The Brush regulator is eminently a practical invention; and though the light produced is not particularly steady, it is quite sufficiently so for general purposes.

The Weston Lamp.

Another lamp with a clutch regulator is that invented by Mr. Weston. The arrangement is in principle very similar to the Brush lamp; the mechanical details are, however, different. A clutch lever is actuated by the armature of an electro-magnet, the coils of which are formed of separate shunt and main wires, exactly as in the Brush regulating solenoid. The armature is prevented from moving too rapidly by a small piston working in a cylinder containing glycerine.

As in the Brush lamp, the positive carbon holder passes through the clutch mechanism, and descends or rises according to the requirements of the arc.

The Pilsen Lamp.

The Pilsen lamp, invented by Messrs. Piette and Krizik,

takes its name from the town in Hungary where it was first manufactured.

The special feature of the lamp is the employment of a biconical or spindle-shaped core of soft iron, which regulates the position of the positive carbon. This core is situated so as to be partly within and partly between two hollow solenoids, through which the electric current supplied to the lamp passes. Owing to its peculiar shape, this core, when accurately counterpoised, has no balanced position, that is to say, it will remain at rest in any position, within a certain range, that may be imparted to it.

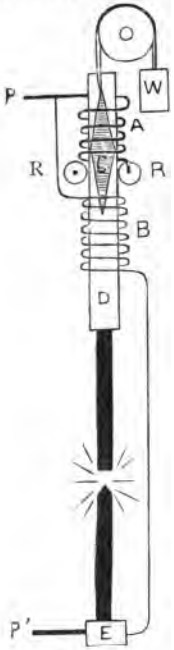

FIG. 43
Pilsen Lamp.

Fig. 43 will help to illustrate the general principle of the lamp. C is the biconical iron core fixed within a brass tube, D, which is counterpoised by the weight W, and free to slide up or down between the guiding rollers, R R. D is the positive carbon holder. A and B are two solenoids surrounding D. A is formed of thick wire and is in the main arc circuit from P through the roller R, the brass tube D, the two carbons, the negative holder E, and the negative terminal P′. The solenoid B is of fine wire, and forms a shunt circuit from P to P′. Now, the resistances of A and B are so calculated that when the arc is of the proper length—usually about a twelfth of an inch—the quantities of current that flow through A and B respectively are such that the effects of A and B on the iron core are equal, and thus, since they are also opposite, the position of the positive carbon is not altered. When, however, the arc lengthens, a greater proportion of current flows through the shunt solenoid B and less through A, the equilibrium of D is destroyed, and the positive carbon descends sufficiently to restore the arc to its proper length when, owing to the peculiar form of C and the restoration of the balance between the main and shunt currents, the motion is arrested.

The length of the arc is thus regulated according to the current by the balance of the currents flowing through the two solenoids, and without the intervention of clockwork or clutch mechanism of any description.

When the lamp is required to maintain a constant focus the counter-weight pulleys are made double, one being twice the diameter of the other, and the negative carbon is caused to move up as it is consumed by being attached to the cord passing over the smaller pulley.

In order to prevent injury to the fine wire of the shunt solenoid should a total extinction of the arc take place, an electromagnetic arrangement is provided which at once switches the current into a thick wire coiled on the outside of the shunt solenoid, and which when in circuit forms another shunt across the lamp terminals.

Carbon pencils about two-fifths of an inch in diameter are generally employed ; but in certain cases, such as the lighting of workshops, plate carbons, as used in the Wallace-Farmer lamp, are found very satisfactory. The resistance of each lamp when burning is 5 ohms, and the electromotive force necessary 40 volts, consequently the current required is 8 ampères.

The lamp has the following advantages :

The feeding of the carbons, and consequently the light produced, is very steady. The mechanism of the lamp is remarkably simple, and not likely to get out of order.

The differential system on which the regulating mechanism is worked renders it possible to burn many lamps in series upon one circuit.

The lamp is usually constructed to hang vertically, but it can be made to work horizontally also.

The Hedges Lamp.

In the lamp invented by Mr. Killingworth Hedges three carbons are employed. The positive electrode consists of two carbon pencils sliding in separate troughs, and inclined to one another so that their point of contact always remains constant, as with one pair of the carbons in the Rapieff regu-

lator. The negative electrode is formed of a single carbon pencil also sliding in a trough, and prevented from sliding too far by a platinum stop which bears on it at its conical end and acts in much the same manner as Siemens' abutment pole. The two electrodes are inclined towards one another at an angle of about 75°, and the arc is formed between them at their lower extremities. The positive holder or trough is fixed rigidly to the lamp frame, but the negative holder can rock upon a pivot so as to lengthen or shorten the arc. A solenoid in the main circuit and a shunt electro-magnet control the position of the movable holder, the solenoid tending to lengthen and the magnet to shorten the space between the carbon points. When this is normal and the arc of proper length, the effects of the solenoid and magnet are balanced; but when the arc becomes too long or too short, the balance is destroyed and the defect remedied. The feeding of the two carbons is thus left entirely to the duplex character of the one and the abutment pole of the other, and all the solenoid and electro-magnet have to do is to regulate the length of the arc according to the current.

The Gülcher Lamp.

The Gülcher lamp has the merit of great simplicity besides that of producing a very steady light.

An electro-magnet, mounted on trunnions so as to be able to oscillate, regulates the length of the arc and the feed of the positive carbon. In front of one of the rounded ends of this magnet passes an iron rod which forms the positive carbon holder, while beneath a prolongation of the magnet core at its other extremity is a fixed iron armature. The magnet coil is placed in the same circuit as the arc. When not in use, the positive and negative carbons are in contact; but when the current passes, the magnet becomes excited, the iron rod forming the positive holder is attracted and gripped by the rounded pole, and the positive carbon is raised by the other end of the magnet attracting the armature, thus rotating itself on the trunnions and raising the positive holder. In this manner the arc

is established. As the carbons burn away and the arc lengthens, the power of the magnet becomes too small to support the positive carbon, which therefore descends a little way; the holder is then again gripped, and the motion arrested. In order to restrain the too violent action of the mechanism, the magnet is furnished at one end with a small iron brake block, which under the varying attractive influence of the magnet bears with more or less force upon the rounded extremity of the latter, and renders the oscillating motion soft and easy.

When these lamps are employed several together, they are not placed in series, but in parallel circuits between the main leading wires from the generator. When this is done they do not interfere with one another, and currents of low electromotive force can be employed.

The Brockie Lamp.

The Brockie lamp is on the clutch system. An electromagnet controls a clutch arrangement which raises or lowers the positive carbon, as in the Brush regulator. By means of a commutator driven from the shaft of the generator, the current supplied to the lamp is automatically interrupted for a very short space of time at fixed intervals of one minute or half a minute. As each of these interruptions occurs, the magnet releases its armature, the clutch ceases to hold the positive carbon holder, and the positive carbon drops upon the negative carbon. The moment the current is restored, the magnet, by means of the clutch, draws up the positive carbon until the arc is of the normal length. The arc is thus regulated at fixed intervals, and the consumption of the carbons compensated for by the descent of the positive carbon. Since the period during which the current ceases is exceedingly minute, the eclipse of the light is of so short duration as to be almost imperceptible.

The electro-magnet is sometimes placed in series with the arc, or, as is now usually the practice, supplied by means of a separate derived shunt circuit. In this latter case it is only the derived circuit that is interrupted by the commutator, the main current being continuous.

Lever's Lamp.

Another clutch lamp is that invented by Mr. Charles Lever. Encircling the positive carbon holder is a clutch clip or washer, which, when tilted, grips the holder and raises it, this being the normal state of matters when the lamp is not burning. The clip and holder are supported by a pivoted lever, which at one end engages the clip and at the other is pulled down by an adjustable spiral spring. Beneath the lever, which is of iron, is an electro-magnet in a shunt circuit, which, when excited, pulls down the clip end of the lever against the force of the spring, thus releasing the clutch and allowing the positive holder and carbon to drop.

When the carbon points come in contact, the resistance of the main circuit becomes much less than that of the shunt; the quantity of current, therefore, that flows through the latter is small, and the magnet is no longer sufficiently powerful to counteract the spiral spring, which consequently depresses one end of the lever, and raises the other, causing the clip to take hold of the holder and raise it. The arc is in this manner established, and subsequent regulations of its length are brought about by the increased resistance of the main circuit causing the power of the magnet to increase, which releases the clutch and permits the positive carbon to descend through a short distance. The principal peculiarity of this lamp is the fact that when no current is passing the carbons are not in contact, the passage of the current causing them first to approach one another and then to recede to a certain fixed distance which can be regulated by a set screw. In a simpler form of lamp on the same principle the lever is dispensed with, the electro-magnet acting directly upon two curved steel springs which bear upon the sides of the carbon holder. These springs keep the two carbons normally apart, but when the arc is too long, or non-existent, the proportion of current that flows through the electro-magnet is sufficient to deflect the springs so as to allow the positive holder and carbon to descend.

The Lever lamp is a decidedly practical invention, and though it has not been much heard of as yet, there is no reason why it should not become well known in the future.

The Akester Lamp.

The Akester lamp is very simple, but as usually constructed is only suitable for supplying one light, for the electrical arrangements do not admit of more than one lamp being in one circuit. The positive carbon holder, which is placed vertically, consists of a metal rod on which has been cut a quickly pitched screw thread, $1\frac{3}{4}$-inch pitch. This holder passes through a screwed nut, having its upper edge milled, and also through the hollow core of a solenoid in the main circuit. A pawl or lever, held down by a spring, engages on the milled surface of the nut, when the latter is raised and prevents its rotation; but when the nut falls beyond a certain point, it becomes disengaged and is free to revolve. The nut is moved up or down by the core of the solenoid; and since the positive holder is itself unable to rotate, it can only descend when the milled nut is free from the pawl. The action of the lamp is as follows: When no current is passing the solenoid core drops, the nut is lowered so as to be free to revolve, and the positive carbon descends so as to rest on the negative carbon. As soon as the current flows, the solenoid attracts the core, raises the nut until it is prevented from revolving by the pawl, and then raises the nut, pawl, holder, and positive carbon together, thus establishing the arc. When the arc becomes long the current becomes weakened, the solenoid drops the core once more, the nut is again free to revolve, and the positive carbon descends until the arc reaches a normal length.

Although the lamp described is not suitable for being worked in series with others, it does not appear that it would be difficult to arrange a regulator with a shunt solenoid so as not to interfere with other lamps on the same circuit.

Abdank's Lamp.

In a lamp invented by Mr. Abdank the length of the arc is regulated according to the current by a clutch actuated by a solenoid in the main circuit. The feed of the positive carbon is controlled by a break acting on a train of wheels. A regu-

lating balance, which can be at any reasonable distance from the lamp, closes a circuit through a magnet controlling the break when the arc becomes too long, and thus allows the positive carbon to descend.

There are many other forms of electric arc lamps, but few of them have been employed to any great extent in this country.

A perfect arc lamp should possess the following qualities:

1. The construction of the lamp should be simple, and its cost small.

2. The light produced should be steady and free from flickering.

3. The mechanism of the lamp should not be liable to go out of order, and the lamp should not require skilled attendance.

4. The regulating mechanism should be such that several lamps can be burnt in series on the same circuit.

5. The lamp should give a maximum of light with a minimum of electricity.

No lamp at present constructed fulfils absolutely all these conditions, but in choosing a lamp for any particular purpose one should be selected that seems best suited to fulfil the conditions that are most important for the particular kind of work for which the lamp is intended.

It does not seem likely that any very great improvements will be made in arc regulators; but here, again, as with dynamos, increased simplicity, and a consequent lowering of the expense of manufacture, is to be expected. The mechanism of modern arc lamps is about as perfect as it is ever likely to be, and the irregularities in the light produced are, for the most part, entirely due to the unequal burning and spluttering of the carbon pencils. It is to be hoped that by improvements in the manufacture of the latter, it will be possible eventually to obviate this rather serious defect.

Electric Candles.

Electric candles are arc lamps in which the carbon pencils are parallel or nearly parallel with one another, the arc being

first formed at one extremity of the candle, and as the pencils are consumed, burning gradually to the other. In order to produce an equal consumption of the two pencils, alternating currents are employed.

The Jablochkoff Candle.

The electric candle invented by M. Paul Jablochkoff has done much to render electric illumination feasable. This candle, which has been much employed in Paris and is at present burning nightly on the Thames embankment, is extremely simple and entirely without mechanism.

As now constructed the candle consists of two carbon pencils, nine inches long and ·156 inch in diameter, placed parallel to one another with an insulating strip composed of sulphate of lime and baryta between them. Kaolin and plaster of Paris have also been employed. Each of the lower extremities of the pencils is fitted into a copper tube, through which the current passes into one pencil and out of the other. The pencils are connected together at the top by a bridge formed of graphite or other conducting material. When the candle is connected to an alternating current dynamo and the latter set in motion, the current passes through the entire length of the pencils and across the conducting bridge. The latter, however, is immediately vaporised, and an electric arc is established across the intervening space. Owing to the alternating character of the current the two carbons burn away at equal rates, and as this takes place the insulating medium is gradually melted. The light of the arc is therefore continuous and uniform.

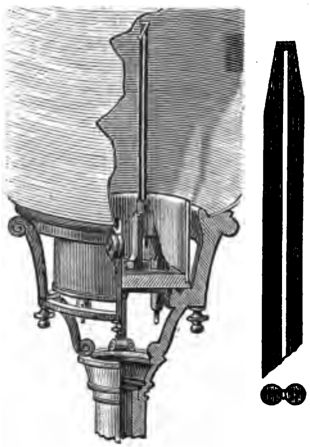

FIG. 44.
The Jablochkoff Lamp and Candle.

Since one candle will only burn for about an hour and a half, four are usually grouped together in one lamp, an automatic switch changing the current from one to another as they are in turn consumed.

The chief objections to the Jablochkoff candles are their expense, the small amount of light produced for the power absorbed, and the incessant variations in the colour and brilliancy of the light. The reasons for these defects are various. A large amount of the current absorbed by each candle goes to melting the insulating medium, and the alternating character of the current precludes the possibility of high efficiency. The variations in the colour and intensity of the light are chiefly due to the insulating medium, which frequently melts irregularly and splutters. Owing to the alternating currents employed, the lamps emit a low humming noise, which is very disagreeable in confined situations.

On the other hand, the lamp has several great advantages. The simplicity of arrangement and the absence of all mechanism obviates the necessity for skilled attendance. The candles can, moreover, be replaced with as great ease as are ordinary wax candles in a candlestick. Jablochkoff candles are usually worked in connection with Gramme alternating machines, several candles being burnt in series on each of the circuits that a machine supplies.

The Rapieff Candle.

In the Rapieff candle, insulating material between the carbon pencils is dispensed with. The candle consists of two carbon pencils fixed almost, but not quite, parallel to one another, the angle inclosed between the two being sufficient to keep the arc constantly at the top. As the pencils burn, the resistance of the lamp remains constant, for the increase in the length of the arc is compensated for by the shortening of the pencils. One of the pencils is attached rigidly to the stand of the lamp, while the other is connected with the armature of an electro-magnet in circuit with the arc. When not burning the pencils are maintained in contact at their upper extremity

by a spring, but as soon as the current passes the electro-magnet separates them. Should the current be momentarily interrupted the carbons fall together, to be instantly separated again by the magnet, the arc being thus re-established. This feature is an important improvement on the Jablochkoff candle, which, when once extinguished, will not relight itself.

The Wilde Candle.

The Wilde candle is almost identical in principle with that of Rapieff. The carbon pencils are, when not burning, maintained in contact by a spring, and when the current passes, drawn into parallelism by an electro-magnet.

The Jamin Candle.

In the Jamin candle the carbon pencils are held together at one extremity by an elastic band. As soon as the current passes, the band is melted and the carbons take up a position parallel to one another. In order to keep the arc at the extremity of the pencils, the conductor conveying the current is made to form a coil of one or two convolutions round the candle from top to bottom, the wire being fixed at a safe distance from the pencils. This arrangement is found to drive the arc to the farthest end of the candle, which is then regularly consumed from end to end.

CHAPTER VII.

SEMI-INCANDESCENT AND INCANDESCENT LAMPS.

Semi-incandescent Lamps of Regnier, Werdenmann, Joel — The Sun Lamp — Incandescent Lamps of Swan, Edison, Lane-Fox, Maxim, Crookes, Gatehouse—The Advantages and Defects of Modern Incandescent Lamps.

SEMI-INCANDESCENT LAMPS.

SEMI-INCANDESCENT or incandescent arc lamps occupy in principle an intermediate position between lamps which produce their light by means of an electric arc, and those in which an incandescent filament is the source of illumination. For the same amount of power absorbed, an arc lamp produces a far greater amount of light than does one or a number of incandescent lamps. A semi-incandescent lamp under the same conditions will produce more light than the incandescent lamps and less than the arc lamps.

Regnier's Lamp.

M. Regnier of Paris has devised an electric lamp on the semi-incandescent principle. A carbon pencil, only ·079 inch in diameter, descends by reason of its own weight upon the edge of a carbon disc. The current is communicated to the pencil at a short distance above its point of contact with the disc, and the intervening carbon is rendered incandescent. As the pencil burns away and descends, a rack in connection with its upper extremity causes the carbon disc to revolve, thus changing the position of the point of contact. The intensity of the current required to work this lamp is remarkably small.

The illuminating power is rather low, but the light produced is extremely steady and uniform.

The Werdermann Lamp.

Another semi-incandescent lamp is that invented by Mr. Werdermann. A small carbon pencil is caused by weights to move up against a carbon block of considerable size and rounded form, which receives the negative current. It is found that this block burns very little, while the pencil is consumed at a rate of from two to three inches per hour. The light is produced partly by the incandescence of the carbon pencil, and partly by the formation of a minute arc between the pencil and the block; this arc being due to a repulsion between the two electrodes sufficient to separate them slightly. Continuous currents are usually employed, but the lamp burns almost as well with those of alternating direction. The lamps are generally connected with the dynamo in parallel circuits. The light produced is remarkably steady, and varies in intensity with the strength of the current employed.

In a more recent type of lamp by the same inventor the carbon block is replaced by a copper cylinder.

The Joel Lamp.

A very practical and efficient semi-incandescent lamp is that invented by M. Joel. In this lamp the light is produced by the heating to incandescence of the end of a thin carbon pencil which forms one electrode, and which is caused to press against a fixed iron cylinder forming the other electrode. The carbon pencil is fed, as it burns away, through jaws of peculiar construction, and that part of the pencil between the jaws and the iron cylinder becomes incandescent. As in the Werdermann lamp, the light is not entirely due to the incandescence of the pencil, for a minute arc is formed, and at the same time a curious flame, formed of incandescent matter, surrounds the extremity of the carbon.

The sectional view of the lamp in fig. 45 will help to explain its construction.

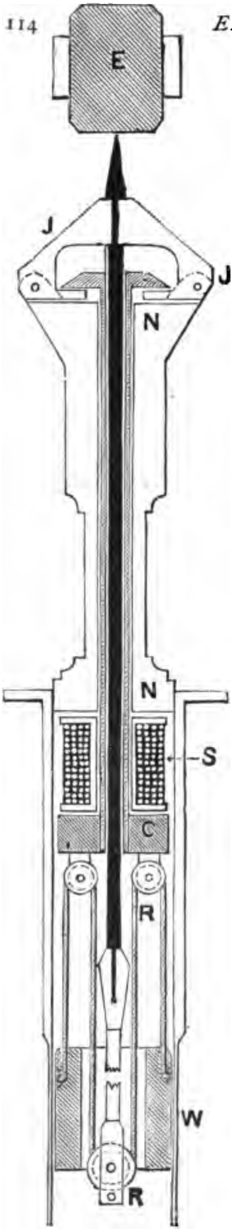

Fig. 45.—The Joel Lamp.

E is the fixed iron cylinder with the point of the carbon pencil pressing against it. J J are the contact jaws which regulate the pressure between the iron and the pencil, and at the same time lead the current to the latter. A weight, W, by means of cords passing over the rollers, R, causes the upward pressure of the carbon pencil. The contact jaws are caused to press upon the pencil through the weight of the metal tube N, which is flanged at its upper extremity and hangs from the cranked position of the jaws. Should an arc of any magnitude form between the point of the pencil and the iron cylinder, a shunt electro-magnet, S, becomes excited, and by means of its armature, C, raises the tube N, and lessens the pressure of the jaws, thus allowing the weight W to raise the carbon pencil into contact with E.

These lamps are made in several different forms to suit different requirements, and in some of these the iron cylinder is placed beneath the carbon pencil, which in this case moves downwards as it is consumed.

The carbon pencils employed are ·197 inch in diameter, and burn at the rate of about three inches per hour. Each lamp is calculated to be of 150 candle-power, and requires about 4 ampères of current with an electromotive force of 12 volts.

The light of semi-incandescent lamps is very steady, and there is none of the disagreeable flare and moonlight effect noticeable when arc lamps are employed.

Since the two electrodes are constantly in contact, very little regulating mechanism is required, and thus a cause of unsteadiness and expense is eliminated. Semi-incandescent lamps are, however, somewhat costly in working, for the carbon pencils are rapidly consumed, and the amount of light produced for a given amount of current is less than in arc lamps.

The Sun Lamp.

The sun lamp—or *lampe soleil*—is in principle intermediate between a semi-incandescent lamp and an electric candle of the Jablochkoff type. An electric arc formed in the ordinary manner between two carbon pencils, is caused to impinge on the surface of a block of Carrara marble which is heated to incandescence.

In fig. 46 C C′ are the carbon pencils inclined towards one another, with a piece of marble, A, between them. D D are pieces of stone or magnesia, and E E is a metal box containing the whole apparatus. B is a small carbon pencil which connects the points of the carbons C C′. When a current is made to flow through the pencils by means of the conducting wires P P′, the small pencil B is greatly heated and eventually consumed. An electric arc is then established across the surface of the marble block A, which becomes exceedingly hot and emits an intense light of slightly yellow hue. The carbon pencils C C′ are prevented from falling out by the narrowing of the holes in which they are placed; and as the carbon consumes, the pencils descend by the action of gravity. Since the marble, when heated, becomes a moderately good conductor, a very long arc can be maintained, and

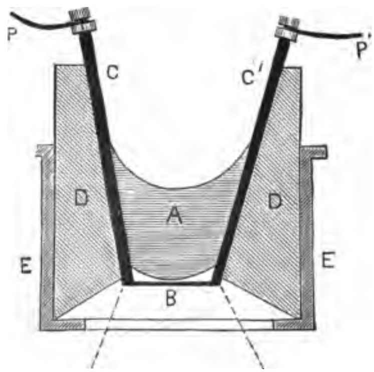

FIG. 46.—Section of the Sun Lamp.

were the current to be momentarily interrupted, the lamp will relight itself so long as the marble remains hot. Owing to the construction of the lamp, the light can be only thrown in one direction, but this, for ordinary purposes, is all that is required.

In the latest form of this lamp, the carbon pencils are in a horizontal line, and impinge by means of springs against the sides of a marble block, through an aperture in which the arc plays. One of the carbon pencils is solid, the other hollow. In the hollow one slides a smaller pencil, which is brought in contact with the point of the solid pencil when the lamp is being lighted. When the small pencil is withdrawn, the arc plays upon the surface of a hollow chamber formed in the marble and open at the bottom. The carbon pencils are six inches long, and are each consumed at the rate of about one-eighth of an inch per hour. The marble block requires renewal every sixteen hours, after which time it becomes disintegrated by the intense heat to which it is subjected. The lamp is made in sizes to produce light of 400 candle-power and upwards.

The absence of all regulating mechanism, and the beauty, steadiness, and softness of the light produced, are the best features of the sun lamp. On the other hand, the efficiency is rather low, and the cost of the renewal of the marble blocks has to be added to that of the carbon pencils. The latter, however, are consumed very slowly; and since the incandescent marble serves as a reservoir of light and obviates flickering, they may be of inferior quality. The sun lamp has thus many of the advantages of the Jablochkoff candle without some of its defects.

INCANDESCENT LAMPS.

Perhaps the most important class of electric lamps are those in which light is produced by incandescence alone and without flame or arc of any description.

When a current of electricity is made to flow through a fine platinum wire, the latter becomes white hot and gives a considerable amount of light. A lamp with a platinum filament is, however, practically useless, as platinum, though very infusible, is unable to bear the intense heat produced by the

electricity, and cannot, therefore, be maintained for any length of time in a state of incandescence. In nearly all modern incandescent lamps the filament, as the incandescent part of the lamp is called, is composed of carbon, which is practically infusible, and can be maintained in a state of high incandescence for a long period provided it be placed in a globe containing a high vacuum.

The best known modern incandescent lamps differ from one another but slightly, and what difference there is between them lies chiefly in the process of manufacture.

The Swan Lamp.

Mr. J. W. Swan, of Newcastle-on-Tyne, has invented an incandescent lamp which bears his name and has been largely employed with very satisfactory results.

The Swan lamp, fig. 47, consists of a spherical glass globe from which all the air, or at least as much of it as possible, has been extracted. In this globe is fixed a tiny carbon filament, manufactured of carbonised cotton thread in the form of a loop, the ends of which are attached by metal clips to two platinum wires, which are sealed into a solid piece of glass and project through the small end of the glass globe. When an electric current of proper strength is passed through the carbon by means of wires attached to the exterior platinum projections, a soft yet brilliant light of perfect steadiness, and with a colour much the same as that produced by gas, is obtained.

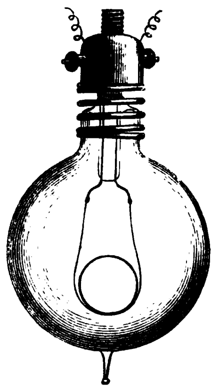

FIG. 47.
The Swan Lamp.

Mr. Swan manufactures his carbon filaments of cotton thread, which is parchmentised with sulphuric acid and carbonised in a closed crucible at a very high temperature. The resulting filament is nearly structureless and homogeneous, and when placed in a high vacuum is able to support a very large amount of heat without

injury. The vacuum in the lamp globe is obtained by means of a modification of the well-known Sprengel air pump, in which a column of mercury descending in a vertical glass tube is the exhausting agent.

The lamp-holder generally employed is very ingenious. It consists of an ebonite button, one end of which is screwed to fit into the lamp bracket. At the other extremity of the button are two small metal hooks which catch the loops formed by the platinum wires projecting from the lamp. A spiral spring between the button and the lamp maintains the contact between hooks and loops, and fixes the lamp. Small binding screws in connection with the metal hooks are fitted at the sides of the lamp-holder for the purpose of attaching the leading wires. In some of the latest holders these binding screws are omitted, and the current enters the holder through two contact pieces at the screwed end of the button, which, when the latter is screwed into the bracket, engage in other pieces connected with the wires.

Swan lamps can be worked with continuous or alternating currents, as found most convenient. The life of each lamp is estimated at 1,000 hours' continuous burning, but some lamps will not last this time, while others have been known to burn for much longer periods without deterioration. The greatest cause of injury is a current the strength of which is constantly changing, at one time being insufficient to keep the lamp at its proper candle-power, and at another heating the filament beyond what it can stand. With such a current the filament deteriorates, and is either broken altogether, or, being partially vaporised, is deposited on the interior of the glass globe, forming a dark film which obstructs the light. It is therefore of great importance that the current employed should be of constant strength, and should never surpass the limits that the lamp can bear; otherwise the lamp will not last. The Swan lamp most in use is of 20 candle-power, but others are manufactured of from $2\frac{1}{2}$ to 100 candle-power, requiring from 1·3 to 3 ampères of current of an electromotive force of from 6 to 120 volts.

The Edison Lamp.

Mr. Thomas Alva Edison, the well-known American inventor, has brought out an incandescent lamp which differs in detail only from that of the Swan.

The Edison lamp, fig. 48, consists of an elongated thin glass globe containing a carbon filament in a high vacuum. The filament is made of carbonised bamboo cane, and is of square section. The bamboo is split into pieces of suitable size, bent into a U-shaped form and carbonised in a furnace in grooved nickel moulds. The ends of the filament, which are wider than the middle portion, are attached by means of copper electrolytically deposited to platinum wires, which are sealed into the glass globe and serve to convey the current. The base of the lamp consists of a screwed metal ring, which fits into the lamp bracket, and a central copper button, the ring and button being attached respectively one to each of the two platinum wires. When the lamp is screwed into the bracket, the ring makes a contact with the metal of the latter, which is in connection with one of the leading wires, while the copper button presses against a metal plate to which the other leading wire is joined. Thus the current entering by one leading wire passes through the bracket, the screwed ring, one platinum wire, the filament, the second platinum wire, the copper button, the metal plate, and the second leading wire in succession.

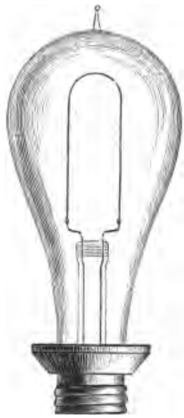

FIG. 48.
The Edison Lamp.

Edison lamps are made in sizes to give 8, 10, 16, and 32 candle-power; the 8-candle lamp working with an electromotive force of 53 volts, the others with 107 volts.

The Lane-Fox Lamp.

The Brush Electric Light Corporation are the proprietors of an incandescent lamp invented by Mr. St. George Lane-Fox.

The lamp consists of an exhausted glass globe containing a

filament of horse-shoe form, which becomes incandescent on the passage of an electric current. The filament is made out of the root of a grass known as French Whisk, and is of circular cross-section. The material is treated with a solution of caustic soda to remove all traces of silica, is washed thoroughly, and while still damp is wound tightly upon small blocks of graphite, which are then buried in plumbago and intensely heated. The filament so formed is next maintained in a state of incandescence in an atmosphere of hydrocarbon gas, additional carbon being in this way deposited upon the weaker portions of the filament, which is thereby strengthened and rendered homogeneous. The filament is supported by two platinum wires, to which it is attached by means of small carbon ferrules. The lamp is exhausted of air by means of a mercurial air-pump of special design.

The current for an 18-candle-power lamp is given as 1·24 ampères with an electromotive force of 60 volts.

The Maxim Lamp.

In the Maxim lamp the filament is made of carbonised cardboard in the form of the letter M. In section it is rectangular and several times as broad as it is thick. Carbonisation is performed in a mould. After it has been fitted into the lamp globe the filament is strengthened by the deposition of carbon from gasoline in much the same manner as in the process employed by Lane-Fox, the lamp globe being filled with the gas, and the filament heated by the passage of an electric current. The heat decomposes the gasoline, and carbon is deposited upon the surface of the filament. Since those parts of the filament which are thinnest are most highly heated, the carbon is more rapidly deposited upon the weak points, and the filament is thus strengthened and rendered of equal resistance throughout.

The Crookes Lamp.

The Crookes lamp, the invention of Mr. William Crookes, F.R.S., is characterised by its durability and economy in

working. The main features of the lamp are a carbon filament, an exhausted globe containing the latter, and a contact socket. The filament is manufactured out of cellulose or vegetable fibre, from which all traces of silica, lime, iron, and other inorganic constituents are removed by treatment with hydrofluoric acid in which these substances—which if allowed to remain lead to the disintegration of the filament—are soluble. A solution of cuprammonia is then used to destroy the structure of the cellulose and to render it homogeneous. After carbonisation the filament is absolutely structureless, and is very dense, hard, and elastic. The filament, which is bent in the form of an M with rounded corners, is attached to two small platinum wires, the junction being effected by painting the joints of contact with a special carbonaceous cement. Imperfections in the carbonised filament are repaired and its resistance reduced by submitting the filament, in a state of incandescence, to the action of an attenuated atmosphere of chloroform, chloride of carbon, or hydrocarbon, from which carbon is slowly deposited upon the weak places. The glass globes are manufactured according to a novel process by means of machinery, the expense of the operation being remarkably low.

The vacuum requisite for the durability of the filament is obtained by a modified form of Sprengel pump, and the final exhaustion is got through the employment of an earthy substance having a high affinity for aqueous vapours and other gases, this substance being introduced into part of the pump and, after the exhaustion has proceeded some length, heated so as to drive off the gas that it has absorbed. After further exhaustion the earthy substance on cooling absorbs the greater part of the remaining gases, and the lamp is sealed up, thus producing a vacuum higher than that obtainable by any other means.

At the base of the lamp a neat socket arrangement is provided, which is so made that by a half-turn of the lamp in either direction contact with the leading wires is made or broken, and the lamp lighted or extinguished.

These lamps are made from 4 to 50 candle-power and to work with an E.M.F. of from 10 to 120 volts, and require 60 watts for 20 candles.

The Gatehouse Lamp.

The Gatehouse lamp, as employed by the Pilsen, Joel, and General Electric Lighting Company, has a filament of peculiar construction. In all other incandescent lamps the resistance of the filament when cold is considerably greater than when the lamp has been burning and the filament has had time to become heated. This is due to the fact that the resistance of carbon decreases with a rise in temperature. Thus the resistance of an 8-candle-power Edison lamp is 112 ohms when cold and only 70 ohms when hot. If, then, a current of too great strength be passed by accident through an ordinary incandescent lamp, the filament, to use a figure of speech, courts its own destruction by offering less resistance to the current the stronger the latter becomes. Now, while carbon decreases in resistance with a rise in temperature, with platinum the exact opposite is the case. In the Gatehouse lamp the filament is composed of three consecutive pieces joined end to end, the middle section being composed of carbon, while the end pieces are spirals of thin platinum wire. When the proper amount of current is passing through the lamp, the carbon alone is heated, the platinum being only slightly warm. Should, however, the current increase in strength, the platinum is heated, the resistance of the entire filament increased, and the strength of the current consequently reduced. By means of this compound filament the patentees hope to make the lamp more durable, since the carbon filament is protected from being heated to too high a temperature.

The filament is inclosed in the usual manner in a pear-shaped glass globe containing a high vacuum. The Gatehouse lamp is made in sizes to give a light of from 5 to 50 candles. With the ordinary 20-candle-power lamp the current required is said to be 1·5 ampères with an electromotive force of 60 volts.

There are many other incandescent lamps ; but as they differ but in small details from those described, it is needless to give accounts of their construction.

Incandescent lamps are undoubtedly more suitable than

any others for the illumination of all confined areas where a perfectly steady light is required. Even the most perfect of arc and semi-incandescent lamps flicker more or less, and besides they are much too powerful for any but very large spaces. Their light is, moreover, cold and painful to the eyes. With a good incandescent lamp, on the contrary, the light is absolutely steady and of a warm and pleasant yellow tint, while the intensity can be anything from 2 to 100 candles for every lamp. Incandescent lamps have, moreover, no mechanism of any description, and when worn out can be replaced by new ones with the greatest facility. As at present manufactured incandescent lamps cannot be depended upon to last, without deterioration, for more than 1,000 to 1,500 hours, though cases have been known in which they have burnt for 5,000 hours without appreciable failing. This fact is owing chiefly to two defects which will require to be remedied, or at any rate lessened, in the future. Firstly, the carbon filament is prone to fail suddenly and without warning, snapping in two at some weak point; and secondly, after having been in use for some time, the carbon begins to volatilise and is deposited in the form of a dark veil on the interior of the glass globe, at the same time weakening the filament and obscuring the light. It is much to be hoped that in the future some means will be discovered for obviating these defects, owing to which the lamps in time become entirely useless and require to be replaced, thus increasing very largely the cost of lighting by incandescence. As it is, the lamps of the present day are found to last rather better than those of a couple of years ago, and there does not seem to be any reason why those of a year or two hence should not be, if not absolutely everlasting, at all events much more durable than those now manufactured.

Another expected improvement is reduction in the cost of manufacture and consequent lowering in price. All the earlier incandescent lamps were entirely made by hand and usually in very small quantities, hence a cheap lamp was out of the question. Machinery is, however, being fast introduced into lamp factories, and this, with the employment of female labour, the influence of trade competition, and the enormous number

of lamps that will be turned out, is certain to have a great effect as regards cost. Lighting by incandescence is not so economical as arc lighting. According to Sir William Thompson, an arc lamp gives ten times the amount of light that an incandescent lamp gives for the same expenditure of power. This may be attributed to the fact that the temperature of the arc is very much higher than what the filament of the incandescent lamp can stand. It must, however, be remembered that with one arc lamp the light all radiates from one spot, while several incandescent lamps can be distributed so as to give an even amount of illumination over a considerable area.

If an incandescent lamp be worked with a current beyond that for which it has been designed, the filament is rendered intensely brilliant, and the economy of the lamp is, as far as light is concerned, increased. In this case, however, the filament will rapidly deteriorate, and the lamp become useless in a very short time. When, on the other hand, too small an amount of current is supplied, the lamp will last for a very long time, but the light will be small and its colour yellow; at the same time the ratio of the amount of light to the amount of energy absorbed will be reduced. The proper amount of current is, therefore, that which produces the greatest amount of light with a maximum of durability for the lamp.

Incandescent lamps can be placed in any position; and since the heat given off is trifling and the amount of support required small, they lend themselves very readily to ornamental and decorative purposes. At the recent electrical exhibition at the Crystal Palace, a very beautiful chandelier of Edison lamps was shown, in which the lamps formed the petals of finely worked glass and brass flowers. The general effect of this chandelier, when lighted, was truly magnificent. Very pretty effects may also be obtained with lamps, the globes of which are of tinted glass, or obscured by treatment with hydrofluoric acid. Since the lamps are entirely contained in an hermetically sealed envelope, there can be no products of combustion, such as the carbonic acid gas and noxious vapours given off by coal gas. Risk of fire is also considerably reduced, for the moment a lamp is broken and the air admitted, the filament is

instantaneously consumed with such rapidity that it is absolutely unable to set anything on fire. Owing to the small area of the filament, although the latter is intensely hot, little or no heat is communicated to the atmosphere surrounding the lamp.

In a recent trial in the Town Hall at Birmingham, the employment of gas to light the hall raised the temperature of the atmosphere 38° in three hours, while the building was equally well illuminated with electricity for seven hours with a rise in temperature of only 2°. Thus, after a period of lighting by electricity 2·33 times as long as by gas, the temperature of the atmosphere was increased by only 1·19th of the amount due to gas.

CHAPTER VIII.

ELECTRIC ACCUMULATORS.

The Storage of Electric Energy—Accumulators of Planté and Faure—The Faure-Sellon-Volcmar Accumulator—Sutton's Accumulator—The Watt Battery—The Elwell-Parkes Accumulator—The Forbes Accumulator—Barnett's Accumulator—The Defects of Modern Accumulators.

THE storage of electric energy has lately attracted a large amount of attention, and is undoubtedly a very important subject. In the case of an electric lamp supplied with current by a dynamo-electric generator, the moment the machine stops, the current ceases, and the lamp is extinguished. Now, in many cases it would be very convenient if this could be prevented. For instance, it may be impossible to keep the dynamo constantly at work, or an accident, such as the breaking of a belt or a defect in the machinery, may render a stoppage unavoidable. The water supplied in towns to the inhabitants is very often turned off during the greater part of the day; storage cisterns, filled when the mains are working, maintaining a constant supply when the water is turned off. In exactly the same way illuminating gas is not supplied direct from the retorts in which it is manufactured, but is first stored in large gas-holders which maintain the supply constant when the retorts are not in use. The storage of electricity is therefore a very important matter, and its possibility no doubt largely contributes to the practicability of electric lighting.

If two platinum plates be immersed in a cell containing dilute sulphuric acid, and an electric current passed between them, the solution is decomposed into its constituent elements, hydrogen being evolved at one plate and oxygen at the other. If the battery be now disconnected from the generator, and the plates connected by a wire and galvanometer, the deflection of

the latter will demonstrate that a current, opposite in direction to the current employed to charge the cell, is now flowing through the wire.

In 1859 M. Planté, a French scientist, invented a storage battery of considerable efficiency in which the platinum plates employed in the above experiment were replaced by pieces of sheet lead. M. Planté's battery was constructed as follows: two thin sheets of lead of considerable area were placed flat with a piece of canvas between them. The whole was next rolled up into a cylinder and immersed in dilute sulphuric acid. On being attached by wires to an electric generator, the sulphuric acid solution was decomposed by the current, one plate becoming covered with oxide of lead, and hydrogen being evolved at the other. When the cell was fully charged, it was allowed to discharge itself through a wire, and the operation was repeated, the current being this time set in the opposite direction. This system of charging, discharging, and recharging was continued until the lead plates became spongy, when the cell was ready for use, and, when once more properly charged, gave a powerful current of high electromotive force.

Ingenious as it was, the Planté cell was of little practical value, and the troublesome method of forming the plates made it very expensive.

During the last few years several storage batteries of improved construction have been brought out; and although there is still great room for improvement, electrical storage is now quite practicable.

The Faure Accumulator.

One of the first inventors to improve upon the Planté battery was M. Faure, who has been successful in producing a practical form of electric accumulator.

The Faure battery consists of lead plates coated with red lead or minium immersed in dilute sulphuric acid. Red lead is what may be called an intermediate oxide of lead, oxygen converting it readily into lead peroxide, while in the presence of hydrogen it becomes reduced to metallic lead. This being so, when a current is sent through a Faure battery, and oxygen

is liberated at one plate and hydrogen at the other, the red lead coating of the first plate in converted into lead peroxide, while on the other metallic lead is deposited. When the charging is completed by all the red lead having been converted into either lead peroxide or metallic lead, if the plates be now placed in circuit, a chemical action ensues by which both plates gradually become identical in condition, and at the same time an electric current is generated in the conductor between the plates, the strength of this current being about 80 per cent. of that of the current employed in the first instance to charge the cell. The direction of the second current is, however, reversed.

In this manner a current of electricity can be made to bring about a chemical change in the elements of a battery, such that when these elements are connected together by a wire, a fresh current of opposite direction, but almost equal strength, is developed in that wire.

The Faure-Sellon-Volcmar accumulator now issued by the Electrical Power Storage Company is an improved form of Faure battery, in which the red lead is inserted in numerous holes cut in the lead plates. These cells are said to give back 90 per cent. of the current necessary to charge them, their capacity is large, and the electromotive force of the issuing current is 2·15 volts for all sizes. When an electric current of great quantity and low electromotive force is required, the cells are joined in parallel circuits, that is to say with all their negative electrodes connected to one conductor and the positive electrodes to the other; while when an electromotive force of more than 2·15 volts is wanted, each of these parallel circuits must contain several cells joined in series, with the negative pole of one cell connected to the positive pole of the next, and so on, each additional cell adding 2·15 volts to the total electromotive force of the resulting current. On the other hand, when a quantity current equal to that given by one cell, and of high electromotive force, is required, a number of cells are connected together in series in a single circuit. The cells are made in sizes to store from 400 to 2,000 ampères of current, the rate of discharge being from about 35 to 160 ampères.

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When the current stored is nearly all exhausted, the electromotive force can be only maintained by switching in more cells. It is, however, best not to withdraw more than 75 per cent. ot the charge, in which case the electromotive force will remain constant or nearly so, during the whole of the period ot discharge.

One of the principal defects of this and nearly all other accumulators is the fact that when a cell or set of cells are allowed to remain charged for any length of time, a layer of sulphate of lead is formed upon the plates, which interferes with the action of the accumulator, and is very troublesome to get rid of. The same defect is noticeable when the accumulator has been out of use for some time.

The extreme weight of accumulators is a considerable disadvantage in many cases. A single cell of the small 400-ampère capacity size weighs nearly 80 lbs.; and as many cells are usually required, a complete accumulator is very heavy. This precludes all possibility of the adoption of the plan advocated some time ago, that the accumulators should be charged at some central station, and carted to the house or place to be lighted, being when exhausted returned for a fresh supply of electricity. Where the accumulator is set up, there it must remain, and the charging must be done by means of wires connected to a dynamo either near the accumulator or at a distance.

There are several other accumulators that have been found to give good results in practice.

In Sutton's accumulator the electrodes are formed of a plate of copper and a plate of lead amalgamated with mercury, the

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Shunt-wound dynamos are usually employed to charge the cells, and the dynamo must be working at full speed before being connected, otherwise the current from the cells will overpower that of the dynamo, or, flowing through the armature may heat the latter or injure it: for the same reason the cells when charged should be disconnected before the dynamo is stopped. The charging current must be constantly in the same direction, and therefore alternating machines are absolutely useless in connection with storage batteries.

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In this manner a current of electricity can be made to bring about a chemical change in the elements of a battery, such that when these elements are connected together by a wire, a fresh current of opposite direction, but almost equal strength, is developed in that wire.

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Shunt-wound dynamos are usually employed to charge the cells, and the dynamo must be working at full speed before being connected, otherwise the current from the cells will overpower that of the dynamo, or, flowing through the armature may heat the latter or injure it: for the same reason the cells when charged should be disconnected before the dynamo is stopped. The charging current must be constantly in the same direction, and therefore alternating machines are absolutely useless in connection with storage batteries.

When the current stored is nearly all exhausted, the electromotive force can be only maintained by switching in more cells. It is, however, best not to withdraw more than 75 per cent. ot the charge, in which case the electromotive force will remain constant or nearly so, during the whole of the period ot discharge.

One of the principal defects of this and nearly all other accumulators is the fact that when a cell or set of cells are allowed to remain charged for any length of time, a layer of sulphate of lead is formed upon the plates, which interferes with the action of the accumulator, and is very troublesome to get rid of. The same defect is noticeable when the accumulator has been out of use for some time.

The extreme weight of accumulators is a considerable disadvantage in many cases. A single cell of the small 400-ampère capacity size weighs nearly 80 lbs.; and as many cells are usually required, a complete accumulator is very heavy. This precludes all possibility of the adoption of the plan advocated some time ago, that the accumulators should be charged at some central station, and carted to the house or place to be lighted, being when exhausted returned for a fresh supply of electricity. Where the accumulator is set up, there it must remain, and the charging must be done by means of wires connected to a dynamo either near the accumulator or at a distance.

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former being the negative and the latter the positive electrode. The two plates, which are perforated, are rolled into a spiral with insulating bands of india-rubber so placed as to keep the dissimilar metals apart. The plates are immersed in a solution of sulphate of copper and sulphuric acid; and when the current passes, lead peroxide is formed on the lead plate, and metallic copper from the copper solution deposited on the copper plate. When the charging is completed, all the copper in the solution is deposited upon the negative electrode; and if the plates are now connected, an electric current is generated in the conductor forming the connection. In another form of this battery the plates are placed in grooves in a trough.

In an accumulator known by the name of the Watt battery the electrodes are of spongy lead, obtained by treating melted lead with steam.

The Elwell-Parkes accumulator is an invention of recent date and good efficiency. The electrodes are of lead, honey-combed by a long immersion in nitric and sulphuric acid solution. These electrodes are placed in a cell containing dilute sulphuric acid, and are charged in the ordinary manner. After being dis-charged they are again charged in an opposite direction, and are then ready for use. The electromotive force of each cell is a little over two volts, and the capacity forty ampère hours; that is to say, sufficient to give ten ampères for four hours, four ampères for ten hours, or any equivalent quantity.

It is said that with this accumulator little or no trouble is occasioned by the deposition of lead sulphate upon the elec-trodes.

An accumulator invented by Professor Forbes has been found to give very excellent results. Each cell has an electro-motive force of 2·5 to 2·75 volts, and is designed to supply a current for either five or ten hours, as required. The quantity of sulphate of lead formed when this accumulator is not working is said to be extremely minute.

Mr. H. T. Barnett has recently brought out an accumulator which presents several novel features. The battery is formed of lead plates with finely divided lead and layers of felt between them, the electrodes being separated by porous plates. The

whole is practically solid, and will stand without injury shaking and other rough usage. There is no danger, moreover, of the acid solution being spilt, as it is entirely contained in the pores of the divided lead and felt. Since the solution is very acid, it attracts sufficient moisture from the air to compensate for evaporation.

It is claimed that only 10 per cent, of the current used to charge the cells is lost, and that the battery is the smallest in proportion to its power that has been produced. The electromotive force of each cell is $2\frac{1}{4}$ volts for $\frac{7}{9}$ of the time of discharge, after which it drops to 2 for another $\frac{1}{9}$, and then to zero. One set of plates is calculated to last for ten years.

It is to be expected that electric accumulators will be largely improved in the near future, both as regards efficiency and expense. At present there is no accumulator in the market a single cell of which can give a higher electromotive force than three volts, if even that amount is obtainable. Now, electric lamps usually require an electromotive force of over 50 volts; for instance, an Edison 8-candle lamp takes 53, and a 16-candle lamp 107 volts; therefore, a large number of cells must be used, and the expense of the accumulator is thereby greatly increased.

Owing to this and the other defects already mentioned, accumulators are at present only used in cases where their employment is absolutely necessary and unavoidable. If, however, the defects can be removed—and there is every reason to hope that this is the case—there can be no doubt that accumulators will be of very great service in almost every branch of electric lighting, and will render the rapid adoption of electricity as an illuminating agent much more certain than if electrical storage was a practical impossibility. At present it is satisfactory to note the great improvements of the last few years, improvements that have rendered possible the adoption of accumulators in certain cases. Still, however, many and serious defects remain, and until these are removed electric accumulators can never have anything like universal employment.

The different ways in which accumulators can be used are described in the next chapter, on Electric Lighting Systems.

CHAPTER IX.

ELECTRIC LIGHTING SYSTEMS.

The Parts of a System—Conductors—Arrangement of Lamps, Conductors, and Generators—Series and Parallel Circuits—Current Regulators—Winding of Dynamo Magnets—The Edison System—Current Regulators of Lane-Fox, Maxim, and Brush—Richardson's Electric Governor—Switches, Cut-outs, Safety Plugs—Systems with Accumulators—Secondary Generators—Putting up of Work.

THE apparatus required for a complete electric lighting system is—

1. The prime mover.
2. The dynamo-electric generator.
3. The leading wires.
4. The lamps.
5. Accessories.

The prime mover, which may derive its power from steam, air, water, or gas, produces mechanical energy, which by means of the dynamo-electric generator is converted into electricity. The leading wires conduct the electricity to the lamps, where either an electric arc is formed or a filament brought to a state of incandescence, and light is given forth.

Under the head of accessories may be mentioned: current regulators, for modifying the strength of the electric currents that reach the lamps; accumulators, for storing these currents and generating them afresh when wanted; secondary generators, by means of which the electromotive force of the currents can be altered to suit different systems of lamps; switches, for arresting the flow of the currents, or altering and diverting their direction; cut-outs, to prevent the extinction of one lamp interfering with the burning of others in the same circuit; safety

plugs, to prevent the generation of heat, and to guard against the dangers of fire ; and all the other minor fittings which an electric system necessitates.

The various prime movers suitable for driving electric lighting machinery have already been detailed in Chapter IV., while in Chapter V. all the best known dynamo-electric generators have been fully described. We have therefore now to deal with the leading wires or conductors through which the current generated by the dynamo passes to the lamps.

According to Ohm's law, $C = \frac{E}{R}$, the strength of an electric current in ampères is equal to the electromotive force of the current in volts divided by the resistance of the circuit through which it is flowing in ohms. Hence, when the electromotive force remains constant, the greater the resistance of the circuit, the less will be the strength of the current. Again, when a current is made to pass through a conductor offering a resistance, a certain amount of the electricity is expended in the production of heat, and is thereby wasted. Moreover, the resistance of nearly all conductors increases with a rise in temperature ; and so, if a conductor offers a sufficient resistance to a current to become perceptibly heated, and at the same time is unable to get rid of that heat, the resistance opposed to the current will be further increased, and the strength of the current reduced. It is therefore obvious that leading wires for electric lighting must be formed of a material that has great conductivity. Turning to the table on page 18, it will be noticed that, with the exception of silver, which is clearly out of the question on account of its costliness, copper is the metal that has the greatest conductivity and the least resistance. Copper has but one-sixth part of the resistance of iron, is flexible and easily formed into wire, and is therefore well suited as a material for electrical conductors. The expense of copper is, however, considerable, and forms a serious item in the construction of systems for electric lighting. Leading wires of iron are sometimes employed for the sake of cheapness, and also because of their tensile strength. Their use is not, however, to be recommended owing to their want of durability, iron being very easily oxidised.

The proper size of electric leading wires must be calculated according to the rule that the resistance of a conductor varies directly as its length, and inversely as the square of its diameter. When R is the resistance per yard in ohms, and D is the diameter of the conductor in inches for pure copper wire—

$$R = \frac{\cdot 000030996}{D^2}.$$

The material of the conductor having been decided on, the next point of importance is the insulation.

If uninsulated leading wires were employed for electric lighting, the current from the dynamo, instead of flowing through the entire circuit of the lamps, would take the path of least resistance and cross between the leading wires.

Bare conductors insulated at their points of support by earthenware or porcelain cups, as used on telegraph lines, are occasionally employed, and have the advantage of cheapness as well as that of leaving the conductor open to the air, which allows of the speedy dissipation of any heat generated by the current. This system is, however, only applicable to overhead wires, which are unsightly and often dangerous; moreover, when currents of high electromotive force are employed, bare conductors are altogether objectionable, for by touching them any one may receive an injurious if not fatal electric shock. Again, in towns where there are many telegraph or telephone wires passing over the houses, bare electric light leads should on no account be permitted, for if, through stretching or breaking, one of the former wires should fall or come in contact with one of the latter, the powerful electric lighting current will be diverted into the small wire, and flowing into the telegraph or telephone instruments, will destroy the fine wire coils of the latter, perhaps causing an outbreak of fire at the same time. In spite of these objections, naked wires are used in certain cases, especially to serve as a return conductor in connection with an insulated leading wire.

Leading wires as generally manufactured are of copper; single wires, or strands of several, being used according to the strength of the current to be carried. The conductor thus

formed is insulated over its entire surface with a layer of gutta-percha, india-rubber, prepared tape, or other similar materials. The larger sized leading wires employed by Messrs. Siemens are composed of a strand of seven to nineteen copper wires insulated with india-rubber and covered with a protective coating of tape saturated with india-rubber. When placed underground leading wires may be protected by a sheathing of wire, or they may be inclosed in metal or earthenware tubes, which, to prevent the access of moisture, may be filled up with pitch, paraffine, or other insulating and damp-proof substance. When this is done, boxes opening into the tubes are placed at regular intervals, these boxes affording the means of examining and testing the wires.

A new form of leading wire has lately been brought out, in which the conductor and insulating medium are inclosed in a lead pipe. In this case no further protection is necessary.

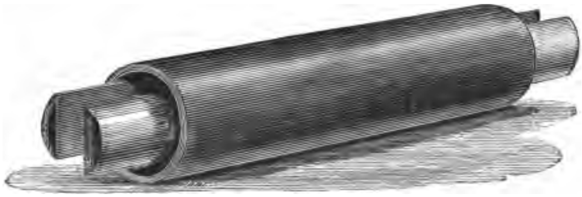

FIG. 49.—Edison Distributing Main.

For conveying current from the main leading wires to incandescent lamps, small copper wires coated with india-rubber and paraffined cotton are employed, the india-rubber being next the wire, which is tinned to prevent chemical action, and the cotton of any suitable colour.

When very flexible conductors are required, as in the case of movable reading lamps, strands formed of very fine copper wire and insulated with silk may be used. The two leads may be twisted together so as to form a cord or cable.

Mr. Edison has invented a form of leading wire which is of novel design and considerable merit. The conductors, which are of copper and of semicircular cross-section, are contained in an iron tube, there being two distinct conductors in every

tube. To prevent them from touching each other or the sides of the tube, and further to guard against the ingress of water, the tubes are filled with an insulating substance sucked into them after the conductors are in position. On this substance becoming solid, the conductors are immovably fixed. One conductor serves to convey the current from the dynamo to the lamps, and the other the return current from the lamps to the dynamo, and thus within a single tube of small diameter are contained and insulated both leading and return conductors.

Joints in electrical conductors require to be made with great care. The usual plan is to bare the ends of the two leads to be united, twist the wires together, or bind them together with another smaller wire, and then solder the joint. The insulating material is then carefully replaced and the joint is completed.

In places of easy access joints are frequently made by means of coupling pieces which fasten on to the wires with screws. Such joints are, however, liable to deteriorate through the oxidation of the parts in contact, and are therefore objectionable in places not open to inspection.

The connection of conductors to lamps, dynamos, and instruments, is effected by means of terminals or binding screws, in which the bare extremities of the conductors are tightly held by adjustable screws, or between pieces of metal.

The proper diameter of leading wires is an important point. If the wire be not of sufficient section for the current that it has to carry, it will become heated, and the insulation will be destroyed by the insulating medium being melted, or perhaps the wire itself will be fused.

The amount of current that a leading wire will carry without *undue* heating—any current, however small, producing a certain amount of heat—depends upon the diameter of the wire and the resistance of the material of which it is formed. Now, we have already seen that the material best suited for leading wires is copper; it therefore remains to find what strength of current copper wires of certain diameters can safely carry.

In England, wire is usually measured as to its section according to a standard known as the Birmingham wire gauge, different sizes being denoted by different numbers. In the

following table are given the principal sizes of electric lighting leads; the size of each being denoted—(1) by the B.W.G. number, (2) the diameter of the wire, (3) the sectional area of the wire. Further particulars given are—the resistance of the wire per 100 yards, its weight per 100 yards, and the amount of current that the wire is able to carry without undue heating. The figures in the last-named column err on the side of safety rather than on that of danger, and represent more what is the general practice in the best installations than the extreme capacity of the wire. The first division of the table refers to a single wire, the second to a cable composed of seven strands.

Table giving the relation between the Resistance and Weight of Electric Lighting, Leads of various Diameters, together with the Amount of Current that can be carried thereby with absolute safety.[1]

B.W.G.	Diameter	Single wire				Seven strands			
		Area	Resistance per 100 yds.	Weight per 100 yds.	Safe working current	Area	Resistance per 100 yds.	Weight per 100 yds.	Safe working current
		inches	ohms	lbs.	ampères	inches	ohms	lbs.	amp.
—	1·00	·7854	·00326	904·78	1,494	—	—	—	—
—	·75	·44178	·00580	509·3	—	—	—	—	—
—	·50	·19635	·01307	226·8	373	—	—	—	—
1	·30	·07068	·03637	81·42	134	·4947	·00519	569·94	940
2	·284	·06334	·04048	73·00	120	·4433	·00578	511·00	843
3	·259	·05268	·04867	68·68	100	·3687	·00695	424·76	701
4	·238	·04448	·05764	51·61	85	·3113	·00820	361·27	595
5	·220	·03801	·06740	43·78	72	·2660	·00962	306·46	506
6	·203	·03236	·07937	37·27	61	·2265	·01134	260·89	430
7	·180	·02544	·1006	29·3	48	·1781	·01437	205·1	338
8	·165	·02138	·1199	24·6	40	·1496	·01712	172·34	284
9	·148	·01720	·1492	19·81	32	·12042	·02131	138·67	228
10	·134	·014102	·1812	16·25	26	·09871	·02588	113·75	188
11	·120	·011309	·2267	13·00	21	·07916	·0324	91·00	150
12	·109	·009331	·2748	10·74	17	·06531	·0392	75·18	124
13	·095	·007088	·3617	8·16	13	·04961	·05167	57·12	94
14	·083	·005410	·4739	6·23	10	·03787	·0677	43·61	72
15	·072	·004071	·6298	4·68	7	·02849	·0899	32·76	54
16	·065	·0033183	·7727	3·82	6	·02322	·1104	26·74	44
17	·058	·002642	·9711	3·04	5	·01849	·1387	21·30	35
18	·049	·001885	1·3598	2·07	3	·01420	·1942	14·50	24
19	·042	·0013854	1·8502	1·60	2	·00969	·2644	11·19	20
20	·035	·0009621	2·665	1·108	1	·006734	·3807	7·75	12
21	·032	·0008042	3·188	·926	1	·005628	·4554	6·48	10
22	·028	·0006157	4·164	·709	1	·00430	·5949	4·96	8
23	·025	·0004908	5·224	·565	—	·003436	·73[illegible]	3·96	6
24	·022	·0003801	6·745	·437	—	—	—	—	

[1] *The Electrician*, March 3, 1883. By permission.

Arrangement of Lamps, Conductors, and Dynamos.

When a single lamp is fed by one dynamo the positive binding screw of the lamp is connected by one leading wire to the positive terminal of the dynamo, while a second leading wire connects the negative lamp and dynamo terminals. Except in the case of lighthouse lamps and other arc lamps of very great power, an arrangement like the above is very rare, for a single dynamo is usually sufficient to maintain several lamps.

In fig. 50 we have a diagram showing the manner in which arc lamps are generally connected to the dynamo that supplies them with current. D is the dynamo, P and P′ being its terminals. L L &c. are the lamps which are joined together in series, and with the leading wires and dynamo form one

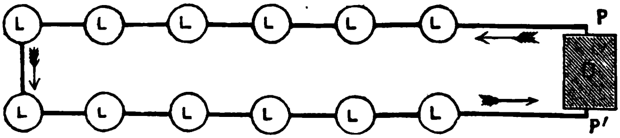

FIG. 50.—Lamps in Series.

continuous circuit. Supposing the current generated in the dynamo to start from P, it enters the first lamp by one terminal, leaving it at the other, then flows on to lamp No. 2, through which it passes in a similar manner, and so on till it has flowed through all the lamps in succession, and arrives at P′, where it again enters the dynamo.

In this system, since every lamp adds to the total resistance of the circuit, the electromotive force of the current required must necessarily be high. For instance, an ordinary Brush lamp requires an electromotive force between its terminals of 45 volts, therefore 20 of these lamps in series would require a current of 900 volts, the current in ampères being practically the same, whether one lamp or twenty are burning. With lamps in series it is therefore necessary to maintain the current constant and to vary the electromotive force according to the number of lamps in circuit, each lamp increasing the total

resistance, and therefore necessitating a higher electromotive force.

Since the extinction of one lamp will cause the extinction of all the others, by interrupting the circuit and consequently the current, arc lamps when burning in series are generally provided with automatic cut-outs, which switch a faulty lamp completely out of the circuit the moment it gets out of order.

In most of the practical applications of the series system, a coil of wire equal in resistance to that of one lamp is switched into the circuit when a lamp is extinguished, and thus the resistance of the whole circuit is maintained uniform. The current is moreover maintained of constant strength and electromotive force, the dynamo field magnets being either separately excited, in which case the magnetic field is bound to be always of constant intensity, or placed in series with the lamps, when as long as the resistance of the latter remains constant, the results

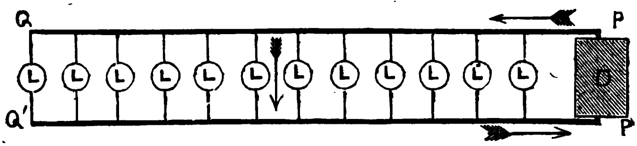

FIG. 51.—Lamps in Parallel Circuits.

are identical. With alternating current machines, separate exciters are of course an absolute necessity.

Electric candles and semi-incandescent lamps are sometimes connected on the series principle. Jablochkoff candles are usually worked with Gramme alternating machines, each candle, or each set of two or four candles, being one of the several separate circuits that that machine is able to supply.

The resistance of semi-incandescent lamps of the Regnier-Werdermann and Joel types is very low, and these lamps may consequently be burnt in series with a current of comparatively low electromotive force.

With incandescent lamps the system usually adopted is that known as the *parallel circuit*, or *multiple arc* system, each lamp forming a separate bridge between the main leading wires.

The arrangement is illustrated in fig. 51, where D is the

dynamo and L L &c. the lamps, P Q and P′ Q′ being the main leading wires.

Since every lamp offers a separate path through which the current can flow between the main leading wires, the greater the number of the lamps the less will be the resistance of the whole circuit, and the greater will be the amount of current required to maintain the lamps at the required pitch of brilliancy. Thus, if a single lamp has a resistance of forty ohms, and requires a current of 1·5 ampères, forty such lamps arranged in parallel circuits will offer a total resistance of only one ohm, but will require 60 ampères of current, the electromotive force required in both cases being the same, namely 60 volts. In this system, should one lamp break, the others are not extinguished, but are unaffected except as regards a slight increase in their brilliancy through the current becoming proportionally stronger per lamp.

When several dynamo machines are employed to drive one set of lamps, and the lamps are connected in series, the dynamos are also grouped in series, so as to produce a current of sufficient electromotive force to overcome the resistance of the lamps. If, on the other hand, the lamps are in parallel circuits across from one main leading wire to the other, the dynamos are arranged in a similar manner, and each additional machine goes to increase the strength of the current and not its electromotive force.

With lamps in parallel circuits the dynamo field magnets are usually separately excited, or placed in shunt or compound shunt and series circuits.

According to the manner in which the lamps are connected with the dynamo in fig. 51, those lamps which are nearest to the dynamo would receive a current of higher electromotive force than those farther removed, and would consequently burn with great brilliancy. In order to obviate this, the conductors may be arranged as in fig. 52, where, since the sum of the resistance between each lamp and the dynamo is constant, the lamps will all burn with equal brightness. Since when currents of very low electromotive force are employed, the main leading wires must be of very large diameter, and since

with many makes of incandescent lamps arranged in parallel circuits, currents of low electromotive force are rendered necessary, a combined parallel circuit and series system is often made use of. Figs. 53 and 54 show two different forms of this system. In fig. 53, two or more lamps joined in series are made to form a parallel circuit. If, as in the illustration, there be four parallel circuits, and each of these contains three

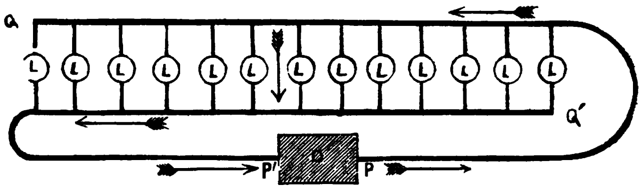

FIG. 52.—Lamps arranged in Parallel Circuits so that they all obtain Currents of equal strength.

lamps in series, there will be twelve lamps in all. Now, if each lamp requires 1·5 ampères of current with an electromotive force of 60 volts, the total amount of current required for the twelve lamps will be $1·5 \times 4 = 6$ ampères, with an electromotive force of $60 \times 3 = 180$ volts; the total resistance of the lamps being 30 ohms. Now, had the lamps been all arranged in separate parallel circuits, the current required would have

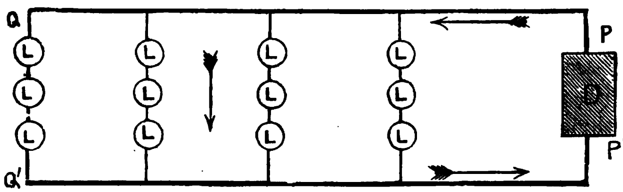

FIG. 53.—Lamps in Parallel Circuits of three in Series.

been $1·5 \times 12 = 18$ ampères, and the electromotive force $60 \times 1 = 60$ volts. Thus, by the combined series and parallel circuit system the current is in this instance one-third, and the electromotive force three times, what would have been the case had all the lamps been in separate parallel circuits. When lamps of very low resistance, requiring currents of very low electromotive force, are employed, this system is of considerable

use, as it reduces the strength of the necessary current, and allows of the same advantage as though the resistance of the lamps was higher.

The disadvantage of the system is that if one lamp is extinguished, those on the same parallel circuit are bound to go out also. This objection is obviated by arranging the lamps as shown in fig. 54, where the breaking of one lamp will but

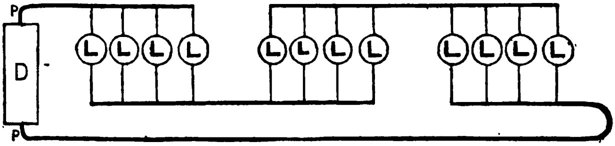

FIG. 54.

slightly affect the other parallels of the same set by giving them more current, and the whole of the lamps by slightly increasing the resistance of the entire circuit.

Current Regulators.

Current regulators are appliances by which the current supplied by the dynamo to the leading wires is regulated in strength according to the number of lamps that are burning. In a series dynamo (see fig. 15, page 44), where the field magnet coils form part of the lamp and armature circuit, any increase in the resistance of the latter causes the magnets to be less powerfully excited, and consequently lessens the strength of the current supplied. For this reason series dynamos are only employed where the resistance of the external working circuit is fairly constant, all the lamps being constantly in circuit, or, at any rate, an equal number of lamps being so. With this system, should a lamp be accidentally extinguished, a resistance equal to that of the lamp must be added to the circuit, a certain amount of power being thus wasted, but the other lamps are not affected.

With a separately excited machine (fig. 14, page 43), in which the current generated by a small separate dynamo is used to excite the field magnets, the intensity of the magnetic

field, and consequently the electromotive force of the current supplied, is constant whatever may be the resistance of the external circuit. This is, however, not the case with a shunt-wound dynamo (fig. 16, page 45). Here part of the current generated in the armature goes to excite the field magnets, the magnet coils forming a shunt or short circuit across the armature collecting brushes.

Now, according to Ohm's law, the respective strength of the two currents that flow through the main circuits and lamps and through the shunt are inversely proportional to the relative resistances of these two circuits. Hence, if the resistance of the external lamp circuit be increased, more current immediately flows through the shunt, the magnets become more intensely excited, and a stronger current is generated in the armature and sent to overcome the resistance. Thus, with the shunt-wound dynamo the intensity of the magnetic field increases with the resistance of the external circuit, and the electromotive force of the current generated is therefore increased as the resistance it has to overcome is augmented. For instance, if a shunt-wound dynamo is supplying current to a number of lamps arranged in series, if several additional lamps be added the resistance of the circuit will be increased, and a current of higher electromotive force will be generated, the strength of the current being thus maintained constant. The only other method adopted for exciting the field magnets of a dynamo is the compound shunt or combined shunt and series system, which is claimed as the invention of Dr. Paget Higgs, by whom it was patented in 1881. In this system (see fig. 17, page 45), the field magnets are wound with two separate wires, one of which forms a shunt and the other part of the main external circuit. The working of the arrangement is such, that when the dynamo is supplying current to lamps arranged in parallel circuits, and hence the resistance of the whole circuit decreases with the number of lamps, the strength of the current supplied is always properly proportioned to the number of lamps that are burning.

It is evident from the above that, theoretically at any rate, if the magnets of the dynamos be excited in a proper manner

the current will be regulated according to the number of lamps that are at any moment in use. In practice, however, it is usual to employ a separate current regulator which shall regulate the current according to the actual demand. There are several methods by which this may be done, the simplest being perhaps that employed by Mr. Edison in his large installations. Mr. Edison's dynamo is shunt-wound, and by means of resistance coils the resistance of the shunt can be increased or diminished at pleasure. At the central station, where are the dynamos, there is an attendant whose duty it is to control the strength of the current supplied. The attendant is provided with a voltmeter, which shows at every instant the electromotive force of the current, and the resistance coils for increasing or diminishing the resistance of the shunt are also under his control.

Let us now suppose that a large number of the lamps supplied by the dynamo are extinguished, and the resistance of the total circuit consequently increased. More current flows through the shunt that excites the magnets, and the electromotive force of the current supplied is increased. The moment, however, this takes place, the alteration is shown by the voltmeter, and the attendant becomes aware that the lamps have been extinguished. By means of a suitable switch arrangement, he inserts a certain number of resistance coils into the shunt circuit, diminishes the strength of the magnets, and thus brings down the electromotive force of the working current to its normal pitch. On the other hand, when more lamps are turned on, the attendant reduces the resistance of the shunt, increases the power of the magnets, and thus allows the machine to produce more current. Since only a few lamps are usually extinguished or turned on at a time, the strength of the current is maintained practically proportional to the work that it has to do.

A system almost identical with the above is employed by Mr. Gordon with his large dynamos. In this case, since the machines are alternating, separate exciters are employed, and the strength of the current supplied by these to the large distributing machines is regulated according to the number of lamps that the latter have to maintain.

Although this system is a very good one when the dynamos and the whole installations are very large, it would clearly be very expensive in small installations if an attendant were always necessary in order to regulate the current. To meet this difficulty, several self-acting current regulators have been devised, and have been found to answer very fairly.

The Lane-Fox current regulator is as follows :

An electro-magnet, through which a shunted portion of the main current passes, controls the position of an armature lever. When the main current is too strong for the work it has to do, the lever is pulled in one direction; when too weak, in the other ; and when the current is exactly of the proper strength, the lever takes up an intermediate position. In another part of the instrument a vertical spindle is caused to rotate at a fixed rate by means of an electro-magnetic arrangement and a local current. At the upper extremity of the spindle is a bevelled cog-wheel, which is so placed between two others fixed on a horizontal spindle, that it can gear with one or other of the latter, or not at all. Attached to the horizontal spindle is an arm, which is at one end caused to rub upon the face of a long semicircular resistance coil, in such a manner that when the arm turns in one direction the current that excites the field magnets of the dynamo has to pass through a greater length of the resistance coil, and is therefore reduced in strength, and when it turns in the other direction, the effect is opposite, and the current is strengthened.

The working of the whole apparatus is as follows :

When the main current becomes too powerful, the armature lever of the electro-magnet is pulled in one direction, and the vertical revolving pinion is caused to gear with one of the cog wheels on the horizontal pinion, so that the latter and its arm turns in such a direction that the shunt exciting circuit is increased in resistance. When, on the other hand, the main current is too weak, the armature lever is pulled the opposite way, the vertical pinion is caused to gear with the other cog wheel, the horizontal pinion turns the opposite way, and by means of the arm and resistance coil the resistance of the shunt exciting circuit is diminished.

Thus, the main current is regulated as required.

The Maxim regulator consists of a very similar piece of mechanism, only instead of altering the resistance of the shunt exciting circuit, and changing the strength of the dynamo magnets, the current when too strong causes the collecting brushes on the dynamo to be rotated to a point of less efficiency, and when too weak to a point where the efficiency is greater. There is, however, a serious objection to this system; for when the brushes are placed so as to weaken the current, a large amount of sparking ensues, which wastes power and destroys the metal of both commutator and brushes.

A current regulator has recently been brought out by the Brush Electric Light Company, in connection with their dynamo for incandescent lighting. The magnet coils of the generator form a shunt circuit, and have connected with them two piles of carbon plates through which the magnetising current must flow. An arrangement of similar design to that employed by Mr. Lane-Fox regulates the pressure between these carbon plates, the pressure being greatest when the main current is too weak, and least when the latter is too strong. Now, the resistance of the pile of plates is diminished by pressure, and so the magnetising current is increased when more power is required from the machine, and diminished when the contrary is the case.

Mr. John Richardson, of the firm of Robey and Company, has patented an electric steam-engine governor which regulates the speed of the engine and dynamo according to the current required.

When used to regulate the current employed for a variable number of arc lamps in series, the governor consists of a double solenoid placed in the main circuit, and of a double iron core which is drawn up by the attraction of the current against the reaction of a spring and counterpoise weight. This arrangement acts on an equilibrium valve in the steam pipe by means of a lever, which opens the valve when the current diminishes in power, and closes it when the current lifts the weight beyond its normal position. It therefore tends to maintain the current of constant strength. In another arrangement the lever controls the expansion of the steam in the

cylinder, causing the steam to be cut off sooner when the current is too strong, and later when too weak. This it does by limiting the travel of an expansion valve, by altering the position of the valve rod as regards a link worked by an eccentric. When the governor is employed in connection with incandescent lamps in parallel circuits, it is caused to regulate the strength of the current so as to maintain a constant electromotive force. The Richardson electric governor has been tested with great care by Professor Silvanus P. Thompson, who has reported very favourably as to its capabilities.

Switches, Cut-outs, and Safety Plugs.

Switches, sometimes also called commutators, are appliances for interrupting the flow of a current, altering its direction, or diverting it into a new circuit. An ordinary on-and-off switch consists of two pieces of brass attached to the ends of the conducting wires, with a third piece of brass arranged so as to be able to form a metallic connection between the first pieces or not as required. Switches which divert or reverse currents are of similar but more complicated construction. The rubbing surfaces of switches should be kept clean and free from grease, and the design of a switch should be such that sparking at the making or breaking of contact is as much as possible avoided. When currents of high electromotive force are employed, contact should be made or broken at more than one point at once. The ordinary switch employed for lighting and extinguishing incandescent lamps resembles in external appearance a gas tap, and is actuated by the turning of a button.

Cut-outs are employed in connection with arc and other lamps, so that should the lamp be extinguished the cut-out automatically switches it out of the circuit and replaces it by a conductor of equal resistance. The automatic cut-out employed in the Brush lamp has already been explained, and may be taken as specimens of this class of instrument. The resistance inserted may be formed of a coil of fine iron wire or a number of carbon pencils arranged in a frame. Where

great accuracy is required, coils of German silver are employed, but the expense of the latter is considerable.

Safety plugs are employed in most installations of incandescent lamps in order to prevent the destruction of the latter, or the dangerous heating of the wires, should the strength of the current, through any accident, become very much above what it should be.

Fusible safety plugs consist of small pieces of fusible alloy, which are introduced into the circuit, and which when the current becomes too strong melt and interrupt the latter. In the Edison safety plug the alloy is of lead and tin, and is introduced into a hole in a screw plug inserted in a wooden block to which the conducting wires are attached. The current in order to pass through the wires must cross by the fusible alloy, and if the current is too strong the alloy melts and the lamps are saved from damage. In some arrangements of this class, tin foil is employed, and in others short lengths of fusible wire, but in all cases the principle is the same.

When lamps are arranged in parallel circuits, each of the latter should be fitted with a safety plug.

Systems with Accumulators.

Although electric accumulators have not yet reached that state of perfection which it may be confidently hoped they will some day attain, still in many cases their use is already attended with considerable advantage.

It is often inconvenient for the engines and dynamos to have to work during the night, and they may be caused to charge accumulators during the day, these accumulators feeding the lamps when required.

Again, by the employment of accumulators the extent of plant required for an electric light installation may be diminished. For instance, when, as is usually the case, the lamps are required to burn for only half the twenty-four hours, an engine and dynamo capable of supplying sufficient current for only half the number of lamps in use may be made to work continuously charging during the day accumulators which

during the night can feed half of the lamps, while the dynamo supplies the rest.

With engines and motors of imperfect construction, which are apt to run unsteadily, accumulators afford a means of maintaining the steadiness of the current, which, when incandescent lamps are in use, means a longer life to the latter, and absence of fluctuation in the light. The total extinction of the lamps through the breaking of a belt or a defect in the engine is also avoided.

When it is advantageous to employ currents in the mains, of an electromotive force higher than that required by the lamps, as it is when the mains are of great length and high resistance, accumulators afford a means of reducing the electromotive force of the currents to what may be required.

When accumulators are employed in connection with a dynamo to supply current to lamps in parallel circuits, both accumulators and dynamo working together, the accumulators are connected together in series in a sufficient number to give the electromotive force that the lamps require, and are made to form a parallel circuit between the main leading wires, just as are the lamps themselves and the dynamo.

Systems with Secondary Generators.

The secondary generators of Messrs. Gaulard and Gibbs afford several important advantages. The principle of these secondary generators is much the same as that of the ordinary induction coil, only the dimensions are much increased. When a current from an alternating dynamo is caused to pass through a coil of wire in proximity to another coil, forming a closed circuit, a current of electricity also alternating in direction is induced in the second coil, and is maintained so long as the first current continues. Messrs. Gaulard and Gibbs's generators are based upon this principle, and by their means currents of very high electromotive force can be made to produce other currents of low electromotive force and great strength. The advantage of this is undoubted. For instance, it is often necessary to generate the current at a considerable distance

from where it is to be used. Now, currents of high electromotive force are dangerous to life, and cannot be used with incandescent lamps arranged in parallel circuits. On the other hand, when currents of low electromotive force are employed their strength must be very great, and the wires that carry them must be of large diameter or they will be heated. Now, when these wires must necessarily be very long and at the same time very large, their expense becomes prohibitive. With secondary generators, however, large conducting wires can be avoided, for the current can be generated in the first instance of small strength and enormous electromotive force, transmitted in that state through small wires, and converted by the secondary generators into other currents of as low electromotive force as is suitable for the lamps. In the same manner one dynamo can be made to supply incandescent lamps in parallel circuits, and arc lamps in series at the same time, a secondary generator reducing the high electromotive force of the current required for the latter to what the former necessitate.

The value of the secondary generator will, however, depend greatly upon its economic efficiency; and as the invention has not yet been employed in any large installations, the latter is at present practically unknown.

General Arrangement of Motors, Generators, Conductors, and Lamps.

The putting up of work is a very important subject, covering as it does a vast number of minor details.

The foundations for motor and dynamo require to be thoroughly substantial, if steady working is to be expected. The speed at which most electric lighting machinery is driven is very high, and unsteadiness is therefore conducive to the speedy destruction of all moving parts.

It is very advantageous when the motor can be coupled direct on to the armature shaft of the dynamo without any belting; and when fast-running motors are employed, and the requisite speed at which the dynamo has to be driven is not very high, the point is one easily attained.

It, however, frequently happens that the speed of the engine not that at which the dynamo must be driven, and in that case belts must be used. These should be very carefully selected. A badly jointed belt frequently causes irregularities in the speed of the dynamo, to such an extent that a decided flicker in the lamps supplied is observable every time a joint passes over the dynamo pulley. Canvas belts work very satisfactorily, as also do the new belts formed of leather link work, which adapts itself without difficulty to the shape of the pulleys, and therefore is not apt to slip, and is at the same time very strong, durable, and easily jointed.

When dynamos are driven by belts it is often an advantage to have an extra fly wheel on the armature shaft in addition to the one on the motor, increased steadiness in working being thereby attained. Extra tightening pulleys, or other arrangements by which the belt can be tightened while the machinery is in motion, are very convenient.

Dynamos should be fixed in a dry place on stone or timber foundation laid in concrete, and the bearing of the armature shaft should be kept well oiled.

Conductors should be well insulated and fixed in positions in which they can easily be reached for testing and repairs.

Continuous currents of over 300 volts and alternating currents of over 200 volts are dangerous to human life, and hence, when currents that pass those limits are employed, great care is necessary as regards the handling of naked conductors.

Arc lamps are generally fitted with glass globes to protect the carbons and arc from the weather, and to prevent pieces of hot carbon that may become detached from falling. The globes may be of clear, ground, or opal glass. Clear globes are certainly the most economical, for they absorb very little of the light, which is emitted with almost the full intensity of the arc. There can also be no question as to the beauty of an unobscured arc light, which in general effect is very similar to brilliant moonlight. The shadows are, however, very intense, and the arc itself is somewhat painful to the eye if looked at for any length of time. Obscured globes are therefore common. Ground-glass globes simply diffuse the light without altering

its bluish colour, while opal globes impart a somewhat yellow tint. Obscured globes, especially those made of ground glass, have a tendency in smoky towns to become black and dirty-looking, which has a bad effect not only when the lamps are lighted, but also by day. Plain glass globes absorb about 10 per cent., obscured globes from 20 to 50 per cent. of the light given by the arc.

Incandescent lamps may be inclosed in clear or obscured globes, which may be white or coloured. A globe of any kind, however, is not a necessity as with arc lamps, for all incandescent lamps have globes embodied in their own construction, which can be obscured and coloured as desired. A very brilliant effect is obtained by silvering one half of the globe of an incandescent lamp, a reflector of great power being thus obtained in a very advantageous position.

Brackets and chandeliers for incandescent lamps have been designed in great varieties, the fact that the lamp is able to burn in any position, the absence of heat, the small size of the necessary wires, being all conducive to the attainment of elegance.

CHAPTER X.

THE ELECTRIC LIGHT IN ITS VARIOUS APPLICATIONS. ITS ADVANTAGES AND COST.

Street Lighting—The Illumination of large Areas, Covered Spaces, Manufactories, Workshops, Theatres, Steam Ships, Railway Trains, Coal Mines—Domestic Electric Lighting—Decorative Effect—Electric Distribution in Towns—The Use of Accumulators—The Cost of Electric Arc Lighting as compared with Gas at the British Museum, the South Kensington Museum—Cost of Electric Lighting by Incandescence—Sir William Siemens' Address to the Society of Arts—Report of Mr. Conrad W. Cooke to the Corporation of Sheffield—Tender made by the Telegraph Construction and Maintenance Company to the Corporation of Nottingham—Mr. Octavius E. Coope's Experiences—Mr. William Crookes' Experiences—The Future of Electric Lighting.

THE electric light is applicable as an illuminant to almost every species of subject. Be the space to be lighted large or small, covered or open to the air, be it a town, a country residence, a steam ship or a railway train, electric lamps suitable for producing the light, and generators to supply these lamps with electricity, can be obtained, arranged to meet all requirements.

When very large quantities of light are wanted, as is the case when large areas have to be illuminated, arc lamps are to be recommended on account of their economy. When the areas are smaller, and the amount of light required consequently less, electric candles, semi-incandescent lamps, and large incandescent lamps of 50 or 100 candle-power are usually employed. Again, for lighting small spaces and buildings incandescent lamps cannot be excelled.

Street lighting may be conducted on various systems. Arc lamps fixed on posts somewhat higher than those usually employed with gas, and situated at rather longer intervals,

have been tried with success in various localities. The lamps must be fitted with globes, which may be clear or obscured according to taste.

The bluish tint of the light from an arc lamp is inclined to produce a kind of vaporous smoky effect, as though the atmosphere were not clear. This can be obviated by employing globes of a slightly yellow colour.

Jablochkoff candles have been much employed in Paris for street lighting, and in this country on the Thames Embankment. Owing chiefly to the unequal burning of the insulating medium, the light of these candles is not very steady and is liable to abrupt changes in colour. They have the further disadvantage of being rather expensive.

Semi-incandescent lamps are applicable to street lighting, and though not so economical as arc lamps the light is generally more steady. The same remark applies to incandescent lamps, which when of 40 or 50 candle-power, and placed on the ordinary street lamp-posts, give an abundance of light of much the same colour as that produced by gas.

A novel method of street lighting by electricity has been tried in America, where it has met with some success.

Arc lamps of very great power are fixed at the top of enormously high masts or light towers, and thus illuminate all the surrounding district. The highest light tower yet constructed is in Cleveland, Ohio. This tower, which is built of iron boiler plate, is 250 feet in height, with a diameter of three feet at the base, and eight inches at the summit. The light is produced by five Brush arc lamps, and is equal to 20,000 candles. Though this arrangement may work very well in the clear atmosphere of America, it does not seem likely that it will ever be of much use in this country, where more than half the light would be absorbed by the air before it reached the ground.

The lighting of large open areas presents much the same features as that of streets. From an electrical point of view, the employment of a few large lamps of great candle-power is more economical than an equal amount of illumination produced by a greater number of smaller lamps. With the latter, however, the lighting is more even, and the shadows less in-

tense; and since the intensity of light diminishes as the square of the distance of its source, the actual difference in cost between the two systems is not so great as might be expected.

For large covered spaces, such as markets, public halls, railway stations, exhibitions, and other places of a similar nature, arc and semi-incandescent lamps may be used, the former being the most economical, while the latter give light of a colour resembling gas, with greater steadiness. Where the building permits, arc lamps are best hung at a considerable height, for though a certain amount of light is thereby lost, the diffusion is better, and the shadows less. In order to soften the light, obscured globes are generally necessary. South Kensington Museum has recently been lighted by means of the sun lamp, in a very satisfactory manner. The lamps are inverted, so as to throw the light on the roof, which serves as a reflector. The illumination is thus very soft and uniform.

Manufactories may be lighted with arc, semi-incandescent, or incandescent lamps, or a combination of these systems, according to their size and the nature of the illumination required.

For very large shops arc and semi-incandescent lamps afford very good general illumination, but incandescent lamps will usually be required as well in close proximity to the various machines. From their burning in any position, and from the absence of heat and fumes, incandescent lamps connected with flexible wires afford remarkable facilities for the illumination of machines in course of construction in engineering establishments.

For the lighting of theatres, music halls, and other places of entertainment, incandescent lamps cannot be excelled for safety and general adaptability. Although the incandescent filament is itself intensely heated, its small size, and the fact of its being totally inclosed in a glass globe from which the air has been withdrawn, render the amount of heat given off extremely small, being not one-sixth of that of a gas flame of equal illuminating power. Again, the nature of an incandescent lamp permits of the generation of no noxious and injurious gases or smoke, which with gas render the atmosphere of theatres unpleasant and stifling, while gilt and decorative work is blackened and destroyed. Danger of fire is moreover re-

duced to a minimum. An incandescent lamp never becomes hotter than can be borne by the hand; while if the lamp globe be broken, the filament is entirely consumed with a rapidity so great that it actually has not the time to set anything on fire, however inflammable. The advantage of this in a theatre, where the scenery and properties are usually of the most flimsy and combustible nature, is simply inestimable.

In the Savoy Theatre, in London, which is entirely lighted with incandescent lamps, the arrangements are of the most complete nature, and give very great satisfaction. No less than 1,158 Swan lamps are employed, of which 824 are on the stage. The dynamos are those of Siemens and are shunt-wound. By means of resistance coils, which can be inserted at pleasure into the exciting circuits, the lamps are entirely under control, and the usual stage effects are given with an amount of certainty and precision which is wonderful to the uninitiated. The sudden changes in intensity so common with the older lime light process are entirely obviated, and one effect merges into another with the proper graduation. The employment of electricity has also a very beneficial effect on the purity of the atmosphere, which remains cool and fresh during the most prolonged plays.

For the illumination of steam ships, incandescent lamps have met with very considerable success, and there can be no doubt as to their being an improvement on the old method of lighting by means of oil lamps. In iron ships the insulation of the leading wires requires special care, and in many cases the ship itself can be employed as a return lead. Dynamos on board ship are often worked direct by fast-speed rotary or three-cylinder engines, belts being thus dispensed with, but belt and frictional gearing is also employed. Arc lamps may be used for lighting the steerage and certain other portions of the ship, and when fitted with the proper reflecting and optical appliances are invaluable as search lights and for illuminating the path of the vessel during the night; arc lamps are also useful to facilitate the loading and unloading of vessels during the night-time.

The lighting of railway trains with incandescent lamps has

been successfully accomplished on the Pulman cars on the London, Brighton, and South Coast Railway. Electric accumulators were employed to produce the necessary current, which was led to incandescent lamps in the various compartments. There does not seem to be any reason why the electric lighting of trains should not be extended to all lines, and the customary oil lamps, which are as a matter of fact very nearly useless, abolished altogether. A small dynamo in the guard's van might be worked by means of a belt connected with one of the carriage axles, a few accumulators serving to maintain the light when the train was not in motion.

The lighting of coal mines by means of electricity is attracting attention. The ordinary safety lamp gives very little light, and has been known in certain cases to have caused explosions. Now, incandescent lamps inclosed in strong lanterns, so as not to be easily broken, would give an abundance of light without any danger whatever. The chief difficulty lies in the leading wires, which are peculiarly liable to mechanical injury, and the insulation of which is injuriously acted upon by the prolonged action of damp. If two of these wires became crossed, and the insulation between them destroyed, the wires might be heated, sparks formed, and explosions originated. A cure for this would be if suitable accumulators, capable of being easily transported with the lamps, were obtainable. Those at present in the market are, however, much too heavy for this purpose, let alone their expense.

For the illumination of ordinary dwellings, incandescent lamps are undoubtedly unequalled. The absence of heat and fumes renders them peculiarly wholesome, while by their substitution for gas many advantages are likely to accrue. Gas has a very injurious effect upon vegetation of all kinds, it destroys the bindings of books and the pigments of pictures, and its general effect is to make everything black and grimy. With electricity, all this is altered, for with incandescent lamps no noxious gases, smoke, or dirt of any description are produced. Instead of being injurious to vegetation, the electric light actually accelerates the growth of plants, and may therefore be employed in conservatories, where gas has been inadmissible.

No fumes or smoke are given off, and thus decorations will retain their freshness for very much longer periods than has been the case hitherto. The small amount of heat generated will be specially welcomed in places where people congregate together. Since a lamp lights itself the moment the current is turned on, no matches are required, and a frequent source of fire is thus eliminated. As already stated, incandescent lamps lend themselves very readily to artistic and decorative effects. The lamps burn in any position, do not heat or blacken objects in their vicinity, and require very little support; moreover, the wires conveying the current are small and easily hidden. For the lighting of ordinary rooms, lamps of 20 candle-power are perhaps the most suitable size. The lamps may be with or without exterior globes, and may be fixed to pendants from the ceiling or wall brackets. In the latter case mirror or opal reflectors placed behind the lamps serve to diffuse the light and have an agreeable effect. A system which has met with some success is to employ a large number of small lamps of 8 or 10 candle-power placed at regular intervals round the cornice of the room.

The switches for turning on the currents to the lamps may advantageously be placed near the door of the apartment, so as to be easily reached by persons entering in the dark. In some cases it might be a good plan to have the switch fixed outside the door. Lamps for passages and servants' quarters are frequently arranged in concave reflectors fixed on the walls, the front of the reflector being covered with wire netting to protect the lamp from injury. A very pleasing arrangement in a conservatory is to suspend the lamps amongst the foliage of the plants, which, instead of being injured, are rather benefitted by the light. Portable reading lamps, which can be moved from one table to another, are very convenient. The necessary current can be led to the lamp by means of flexible silk-covered wires, or two small brass plates in connection with wires may be fixed in the centres of the tables, there being corresponding plates at the base of the lamp stand. When the lamp is placed in position on the table, the current passes and the lamp lights.

Arc lamps are of little use in private houses, but may be occasionally employed to light approaches, gardens, courts, and very large apartments. For the latter, their unsteadiness is their chief disadvantage.

Semi-incandescent lamps of the sun or Joel types can be employed in large apartments and in entrance halls, passages, and staircases.

It cannot, however, be denied, that for all domestic purposes incandescent lamps are preferable, for the light produced is much more steady, and there is no regulating apparatus to get out of order or carbons to change.

It seems probable that before very long electricity will be supplied to houses in towns as are now water and gas. Central stations provided with large steam or other motors and huge dynamo machines will generate the current, which will be distributed by means of electric mains beneath the streets. In every house will be an electric meter, which will check the amount of electricity consumed, which will be paid for in much the same manner as is now the case with gas.

According to the orders of the Board of Trade, under the New Electric Lighting Act, the unit of electricity supplied is to be 'the energy contained in a current of 1,000 ampères flowing under an electromotive force of one volt during one hour;' in other words, 1,000 volt ampères for one hour or 1,000 Watt hours. The difficulties of a system of electrical distribution would be much reduced if a cheap and effective accumulator were obtainable. Without accumulators a constant supply of current can only be obtained by keeping the machinery at the central station continually at work, which requires in practice that all machines should be duplicate. Now, if accumulators could be arranged in all houses, they could be made to act like cisterns do in the case of water, and the current from the central station could be interrupted during certain periods in every twenty-four hours. At present it seems as if separate street mains will be requisite to supply currents of high electromotive force as suitable for arc lamps in series, and currents of low electromotive force for incandescent lamps in parallel circuits. Accumulators would obviate this necessity, for the current

supplied to charge the latter could be invariably of the same electromotive force, and the current could be altered as required to suit the lamps by different arrangements of the accumulator cells.

For places where electricity is not supplied from a central station, consumers must generate it for themselves. Where gas can be obtained, gas engines to work the dynamos are very convenient, and if placed in the cellar are out of sight and hearing. In several instances, it has been found more economical to employ gas to work a gas engine, and thus produce electric light, than to use the gas directly by burning it. Where accumulators are employed a very small gas engine will suffice, the engine working continuously day and night, while the current is only required for a few hours. With accumulators, moreover, the engine employed need not be specially adapted for the work, unsteadiness in working in this case being unimportant. Thus, in places where farm or other engines already exist, they can be made use of without requiring any alterations. Where water-power can be obtained for nothing, the cost of electric lighting is very greatly reduced, the wear and tear of the machinery and the renewal of the lamps being the only items of expense after the first cost of the installation.

COST.

We now come to the question of cost, which in many cases is a supreme consideration.

The cost of an electric installation depends upon so many circumstances, that arriving at any very definite result in questions of this kind is always extremely difficult.

The following may, however, be taken as fair examples of the average cost and working expenses of electric installations on the arc, semi-incandescent, and incandescent systems.

During the last three years, the reading room and other portions of the British Museum have been lighted by Messrs. Siemens with their pendulum arc lamps. The total illuminating power was 18,800 candles, produced by four large lamps, each of 3,000 candle-power, and several smaller ones of 300

candle-power. The total expenses, including maintenance, fuel, carbons, and attendance, were, between October 28, 1879, and the end of February 1880, during which the lamps were burning 360 hours, 108*l.* or at the rate of 6*s.* per hour for a total illumination of 18,800 candle-power.

As to the comparative cost of gas, five cubic feet of gas when burnt in a suitable burner are capable of supplying a light of 16 candles for one hour. 18,800 candles would therefore require 5,875 feet of gas per hour. This at the average price of 3*s.* per 1,000 cubic feet would mean an expenditure of 17*s.* 7*d.* per hour, or 11*s.* 7*d.* more than the cost of an equal amount of illumination produced by means of electricity.

To take another example: the following are particulars as to the relative cost of lighting by means of gas and electricity at the South Kensington Museum.

The Lord President's Court, which is 138 feet long and 114 feet wide and 42 feet high, was until lately lighted by gas, the consumption of which amounted to 4,800 cubic feet per hour, which at 3*s.* 4*d.* per 1,000 cubic feet cost 16*s.* per hour, or, taking the Museum to be lighted for 700 hours in the year, 560*l.* per annum.

At present the building is illuminated by means of Brush arc lamps, which, with the expenses of carbon, fuel, and attendance included, cost 3*s.* 10*d.* per hour, or about 134*l.* per annum; to this must be added about 100*l.* to cover interest on capital, depreciation, and repairs; so the total working expenses may be taken at 234*l.* per annum as compared with 560*l.* when gas was employed.

The economy of semi-incandescent lamps is not so great as those in which there is an actual arc. Electric candles of the Jablochkoff type are expensive because of the low percentage of the light produced for the power expended, and also because of the process of manufacture being rather costly. With lamps of the sun type, the cost of the renewal of the marble blocks has to be added to that of the carbons, but the latter are consumed more slowly than is the case with ordinary arc lamps.

The expense of lighting by means of incandescent lamps is

considerably greater than when arc lamps are employed, as may be gathered from the following data.

Under favourable conditions, and with large arc lamps, the light produced is about 1,200 candles for every horse-power of energy absorbed by the dynamo machine.

Again, when incandescent lamps are used, the maximum candle-power obtainable is 200 candles per horse-power, or only one-sixth of that obtained with arc lamps. Moreover, it is not usual to get more than 160 to 180 candles, eight or nine 20 candle-power incandescent lamps being, as a rule, the number most economically worked with one horse-power of energy.

The following figures, relative to lighting with incandescent lamps on a large scale, are taken from an address delivered before the Society of Arts on November 15, 1882, by Sir William Siemens, F.R.S.:

ESTIMATED COST OF AN ELECTRIC LIGHTING INSTALLATION TO LIGHT THE PARISH OF ST. JAMES'S, LONDON, WITH 64,000 INCANDESCENT LAMPS, EACH OF 16 CANDLE-POWER.

Capital Expenses.

	£
Engines, boilers, dynamos, &c.	140,000
Conducting mains	37,000
Total cost of installation	£177,000

Or £2 15*s.* 3¾*d.* per lamp.

EXPENSES OF MAINTENANCE OF 64,000 LAMPS, BURNING 6 HOURS PER DAY, OR 2,190 HOURS PER ANNUM.

	Per annum £
Fuel	18,300
Wages, repairs, and sundries	6,000
Interest on capital at 5 per cent.	8,900
Depreciation at 2½ per cent.	4,400
Management	3,400
Renewal of lamps, each lamp lasting for 1,200 hrs.	28,800
Total working expenses	£69,800

Or 21*s.* 9½*d.* per lamp per annum.

With gas it would take 5 cubic feet per hour to produce the same luminous effect as one incandescent lamp of 16 candle-power. This at six hours per day would mean an annual gas

consumption of 10,950 cubic feet, the value of which, taken at the rate of 2*s.* 8*d.* per 1,000, gives an annual charge of 29*s.* per lamp, or 7*s.* 2½*d.* more than the cost of an electric lamp of the same illuminating power.

Report of Mr. Conrad W. Cooke to the Corporation of Sheffield.

ESTIMATED COST OF AN INSTALLATION COMPRISING 10,000 LAMPS OF 20 CANDLE-POWER. CAPITAL REQUIRED.

	£
Six 250 horse-power compound steam engines	4,500
Six Lancashire boilers	4,680
Pipes, connections, and belts	2,000
Twelve 1,000-light dynamo-electric machines	9,600
Fixing, starting, &c.	1,000
Mains and distributing plant	8,880
Land and buildings	10,000
Contingencies, engineering, &c. at 10 per cent.	4,066
Total capital expense	£44,726

Or £4 9*s.* 5*d.* per lamp.

COST OF MAINTENANCE PER ANNUM, LAMPS TO BURN 3,000 HOURS PER ANNUM.

	Per annum £
Coal, at 7*s.* per ton	1,582
Oil and stores	250
Wages	956
Repairs	2,872
Management	500
Interest on capital at 5 per cent.	2,236
Total working expenses	£8,396

That is to say, 16*s.* 9½*d.* per lamp per annum, or ·067*d.* per lamp per hour.

To this must be added about 8*s.* for the renewal of the lamps, and the yearly expense is thus brought up to £1 4*s.* 9½*d.* per lamp of 20 candles per annum.

The following is an abstract of specification and tender furnished by the Telegraph Construction and Maintenance Company to the Corporation of Nottingham. Installation to consist of five Gordon dynamos with engines and boilers, capable of maintaining 6,000 Swan lamps, each of 20 candle-power, during 16 hours per day, and one-third of that number

of lamps during the remaining 8 hours. There to be also suitable engine house, travelling crane, distributing mains, regulating apparatus, and other appliances. The price to be 220,000*l.*

ESTIMATED COST OF WORKING 60,000 LAMPS, EACH LAMP TO BURN FOR 2,500 HOURS PER ANNUM.

	Per annum £
Depreciations	10,000
Coal	9,685
Oil and stores	830
Wages	5,393
Rents, rates, office expenses	1,500
Renewal of lamps	15,000
Total annual expenditure	£42,408

Cost of gas.—60,000 burners (each of 12 to 14 candle-power), each burning 5 cubic feet of gas per hour, for 2,500 hours per annum, burn 750,000,000 cubic feet, which with gas at 2*s.* 6*d.* per 1,000 cubic feet costs 93.750*l.*

If consumers are charged the same for each Swan lamp of 20 candle-power as for each gas burner of 14 candle-power, this gives:

	£
Revenue	93.750
Expenditure	42,608
Profit	£51,142

Or a dividend on 220,000*l.* equal to $23\frac{3}{16}$ per cent. per annum.

It will be noticed that there is a considerable difference in the expense per lamp per annum in the above estimates, and it is very probable that in every case the figures given are rather too advantageous to electricity; still, it cannot be doubted that, especially in large installations, lighting with electric incandescent lamps is more economical than when gas is employed.

As to the cost of employing electric lighting in country houses, the question does not admit of a definite answer, for such items as the price of coal vary in different localities to such an extent as to make precise estimates impossible. Again, in many places it is feasible to employ water-power to drive the dynamo, and the working expense of the installation is thus very materially reduced.

In a letter to the 'Times' of January 16, 1883, Mr.

Octavius E. Coope gave the following particulars relative to the actual cost and working expenses of an installation of incandescent lamps in a country house.

COST OF INSTALLATION OF 200 LIGHTS, EACH OF 18 CANDLE-POWER.

	£	s.
12-horse-power engine and boiler	300	6
Shafting and foundations	65	0
Four dynamo-electric machines	405	0
200 incandescent lamps	55	0
200 sockets	10	0
Cables, wires, switches, cut-outs	66	4
Cutting, and making good, walls and floors . .	60	0
Erection, laying of wires, carriage . . .	90	0
Buildings	150	0
Chandeliers and brackets	268	18
Total cost	£1,470	8

WORKING EXPENSES, EACH LAMP BURNING 1,150 HOURS PER ANNUM.

	Per annum £	s.	d.
Coal	38	10	1
Engine driver at 30*s*. per week	78	0	0
Renewal of lamps	38	5	0
Depreciations on machinery at 10 per cent. . .	74	0	0
,, conductors at 5 per cent. . .	4	0	0
Total working expenses	£232	15	1

Or ·97 of a farthing per 18-candle-power lamp per hour.

To produce an equal amount of illumination with gas, the estimated cost of the necessary plant was 1,333*l*. 18*s*. and the estimated working expenses 400*l*. per annum. Hence it appears that though the prime cost of the electrical installation was rather more than what a gas installation would have required, still the annual expenses in the latter case would have been 167*l*. 4*s*. 11*d*. in excess of those of the electric installation.

The figures relative to working expenses given above, form an estimate founded upon three months' actual trial. In a second letter to the 'Times' of January 25, 1884, Mr. Coope gives the actual results of a year's working.

ACTUAL WORKING EXPENSES FOR ONE YEAR, EACH LAMP BURNING 1,823 HOURS.

	£	s.	d.
Coal, small, at 13*s.* 6*d.*, mixed with coke at 18*s.* per ton	90	0	0
Wages, engine driver and lad	79	14	0
Renewal of lamps, 300 at 5*s.*	75	0	0
Oil, cotton waste, &c.	20	0	0
Repairs	5	8	1
Sundry small items and expenses	7	16	8
Depreciation on machinery at 10 per cent.	78	0	0
,, conductors at 5 per cent.	4	0	0
Total working expenses	£359	18	9

Or ·95 of a farthing per lamp per hour.

It should be noticed that the lamps were actually employed for 1,823 hours instead of for 1,150 hours as intended; and hence, though the actual working expenses for the year exceeded the estimate, the expense of each lamp per hour was found in practice to be less than had been anticipated.

It must be also remembered that while the employment of gas speedily soils the ceilings and walls of rooms, and destroys all decorations, incandescent electric lamps have no such evil effects, and therefore by the use of the latter a considerable amount of otherwise necessary expense is avoided.

In a letter to the 'Times' of June 5, 1882, Mr. William Crookes gives his experience as to the cost of a small electric lighting installation in a town house, the electricity being generated on the premises.

The installation consisted of a small Bürgin dynamo, a 3½-horse-power Otto gas engine and 50 lamps, 29 of the latter being of 20 candle-power, and 21 of 5 candle-power. Owing to the necessity that there should be absolutely no smell or noise, it was found necessary to add silencing chambers to the air inlet and exhaust pipe of the gas engine, and also to carry the products of combustion to the roof of the house. Owing to the obstruction thus put in the way of the free working of the engine, the available horse-power was reduced from 5, which the engine was capable of developing under favourable circumstances, to 2. On account of this the dynamo could only be

driven at half power, when much of its efficiency was necessarily lost.

The total expense of engine, dynamo, lamps, and wiring came to about 300*l.*

The dynamo, giving as it did 11·5 ampères of current through an external resistance of 12 ohms, was able to supply twenty-two 20-candle-power lamps at once, and this with an expenditure of gas of about 550 cubic feet in five hours, which at 3*s.* 2*d.* per 1,000 is 1*s.* 9*d.*; this at the rate of five hours per night being 2*l.* 9*s.* per month, or 31*l.* 17*s.* per annum.

To light the same rooms with gas would have taken 30 gas burners, each burning 5 cubic feet per hour, or 750 cubic feet altogether in 5 hours, this costing 2*s.* 4½*d.*, or 3*l.* 6*s.* 6*d.* per month, or 43*l.* 4*s.* 6*d.* per annum.

The expenses, therefore, per month stand as follows:

	£	s.	d.
Electricity—			
Gas consumed in engine	2	9	0
Engineer once a week to clean and oil machinery	0	10	0
	£2	19	0
Lighting by gas alone	3	6	6
Balance in favour of electricity, per month	0	7	6
Or per annum	4	17	6

Interest on capital and depreciations are not charged, but these, Mr. Crookes maintains, were more than counterbalanced by the incidental advantages of electric lighting, such as the absence of the effects of gas upon ceilings, decorations, books, and furniture, together with the increased purity of the air and the reduction in the risk of fire.

Thus, even on a very limited scale, with a gas engine and dynamo working under enormous disadvantages, Mr. Crookes found that to light his rooms by electricity was not only better in every way than with gas, but also that of the two illuminating agents the former was the more economical.

It seems probable that any improvements in electric lighting that may be made during the next few years will have a considerable influence on its cost.

It is likely that competition and the use of machinery

will reduce the price of lamps, dynamos, conductors, and fittings ; that lamps will be made to last for much longer periods without deterioration ; that improvements in the construction of accumulators will reduce their expense and weight, and increase their efficiency, and thus render their application almost universal ; and, lastly, that the resources of nature will be taken into account, and the enormous energy of rivers and tides, energy which is now running to waste, will be utilised to drive electric lighting machinery.

Electricity as an illuminating agent is now upon its trial, and a few years will decide whether it is able to take the place of gas. In the opinion of many, the success of the new agent is already assured, and certainly it seems not improbable that, until supplanted by some fresh rival, electricity will furnish the light of the future.

APPENDIX.

Accumulator.—In electrical science, a secondary or storage battery, for the storage of electric currents.

Ammeter.—An instrument for measuring the strength of an electric current in ampères.

Ampère.—The unit of strength of current.

Arc.—An electric discharge between two electrodes.

Armature.—That part of an electric generator in which the current is induced. A piece of iron or steel acted on by a magnet.

Bobbin.—A coil capable of rotation.

Brush.—The spring that rubs on the commutator strips and leads off the current.

B.W.G.—Birmingham wire gauge, by which wire is usually measured.

Candle.—The English unit of illuminating power.

Carbon.—An elementary substance employed to form the electrodes and filaments of electric lamps.

Carcel.—The French unit of illuminating power.

C.G.S. system.—The centimetre gramme second system of measurements.

Cheval vapeur.—The French unit of power, equals 735 watts.

Circuit.—The path through which an electric current flows. In an electric system the *internal* circuit is that part of the circuit formed by the generator, while the *external* circuit is that formed by the conductors and lamps.

Coil.—A circuit formed by a wire arranged in many symmetrical convolutions.

Comb.—Another term for a brush.

Commutator.—An instrument for changing the direction or the path of an electric circuit.

Conductivity.—The facility with which a substance can convey an electric current.

Conductor.—A substance capable of conveying an electric current.

Core.—In an electro-magnet, the iron that becomes magnetised. In a cable, the central conducting substance.

Coulomb.—The unit of electric quantity.

Current.—A flow of electricity along a conductor.

Cut-out.—An automatic arrangement for switching a defective electric lamp out of a circuit.

Dynamo.—Short for dynamo-electric generator. A machine for generating electric currents.

Dynamometer.—An instrument for determining the power absorbed by a machine.

Dyne.—The C.G.S. unit of force.

Electrode.—One of the poles of an electric generator. One of the points between which an electric discharge or arc takes place.

Electro-dynamometer.—An instrument for the measurement of electric currents.

Electro-magnet.—A magnet, the power of which is obtained by the inductive action of an electric current upon an iron core.

Electromotive force.—Often written E.M.F. The force that tends to start an electric current.

Erg.—The C.G.S. unit of work done.

Farad.—The unit of electrical capacity.

Field magnet.—In a dynamo, the magnet that produces the magnetic field.

Filament.—That part of an incandescent lamp that becomes incandescent.

Foot-pound.—The practical unit of work done.

Force de cheval.—Another name for *cheval vapeur.*

Fusible plug.—A safety arrangement to prevent the fusing of electric conductors.

Galvanometer.—An instrument for measuring electric currents.

Helix.—A coil of several convolutions in the form of a corkscrew.

Horse-power.—Often written H.P. The English unit of power, equals 746 watts, or 33,000 foot-pounds per minute.

Incandescence.—The luminous appearance of intensely heated bodies.

Induction.—The effect of a magnet upon a body. The effect of an electric current upon a body.

Insulator.—A substance offering a very high resistance to electric currents. A substance of very small conductivity.

Joule.—The unit of heat.

Kilogrammetre.—The French unit of work done.

Lines of magnetic force.—The lines of force in a magnetic field.

Magnet.—A piece of iron or steel capable of attracting iron and steel bodies, and of inducing electric currents in conductors moved in its vicinity.

Magnetic field.—The area through which a magnet exerts its influence.

Mega.—A prefix representing *one million times.*

Micro.—A prefix representing *the one-millionth part of.*

Milli.—A prefix representing *the one-thousandth part of.*

Multiple arc.—An arrangement of lamps or generators, in which each lamp or generator opens a separate path through which the electric current can flow.

Negative (–).—The negative terminal of a generator is where the positive current re-enters the generator after having traversed the external circuit. The negative electrode of a lamp is the electrode which receives the positive current last.

Ohm.—The unit of electrical resistance.

Ohm's law.—When C is the strength of the current in ampères, E the electromotive force in volts, and R the resistance of the circuit in ohms, $C = \frac{E}{R}$.

Photometer.—An instrument for measuring the intensity of light.

Polarity.—When a magnet is suspended so as to be free to turn in any direction, it takes up a position in which one end points towards the north and the other towards the south. The former is called the north and the latter the south pole of the magnet. Similar poles repel, and dissimilar poles attract one another.

Pole.—The extremity of a magnet. An electrode or terminal of a generator.

Positive (+).— The positive terminal of a generator is where the positive current leaves the generator. The positive electrode of a lamp is the electrode that first receives the positive current.

Potential.—In electric science, corresponds to pressure or head in hydraulics. Electromotive force is due to difference of potential.

Resistance.—The opposition that an electric current meets with in traversing a conductor. The converse of conductibility.

Series.—A method of connecting lamps and generators so that they form one continuous circuit.

Shunt.—A derived circuit through which passes part of the current flowing through a main circuit.

Solenoid.—A form of hollow electro-magnet in which the armature consists of a cylindrical core which is sucked into the interior of a coil of wire.

Switch.—A form of commutator.

Tangent galvanometer.—A form of galvanometer for measuring very strong electric currents.

Terminal.—The point where an electric current enters or leaves an electrical instrument.

Volt.—The unit of electromotive force.

Voltameter.—An instrument for measuring electric currents according to the amount of chemical action that they produce.

Voltmeter.—An instrument for measuring the electromotive force of electric currents.

Watt.—A unit of power. Equals ten million ergs per second.

Watt-meter.—An instrument for measuring the energy of electric currents.

Weber.—The former name of the ampère.

Wheatstone's bridge.—An instrument for measuring resistances by balancing the unknown by the known resistance.

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